

MARINE ENVIRONMENT PROTECTION
COMMITTEE
65th session
Agenda item 2

MEPC 65/2/5
26 October 2012
Original: ENGLISH

HARMFUL AQUATIC ORGANISMS IN BALLAST WATER

Application for Basic Approval of the Blue Zone™ Ballast Water Management System

Submitted by the Republic of Korea

SUMMARY

Executive summary: This document contains the non-confidential information related to the application for Basic Approval of the Blue Zone™ Ballast Water Management System in accordance with the *Procedure for approval of ballast water management systems that make use of Active Substances (G9)* adopted by resolution MEPC.169(57). This document contains a summary for translation purposes.¹

Strategic direction: 7.1

High-level action: 7.1.2

Planned output: 7.1.2.4

Action to be taken: Paragraph 15

Related documents: BWM/CONF/36; MEPC 53/24/Add.1; MEPC 57/21; MEPC 58/2/4; MEPC 59/2/13; MEPC 61/2/15; BWM.2/Circ.13/Rev.1 and BWM.2/Circ.37

Introduction

1 Regulation D-3.2 of the International Convention for the Control and Management of Ships' Ballast Water and Sediments stipulates that ballast water management systems which make use of Active Substances to comply with the Convention shall be approved by the Organization, based on a procedure developed by the Organization.

2 The *Procedure for approval of ballast water management systems that make use of Active Substances (G9)*, adopted by resolution MEPC.169(57), defines the principal aspects to be documented by data or testing (MEPC 57/21, annex 1, paragraph 4.2.1) and some basic principles for risk evaluation (MEPC 57/21, annex 1, paragraph 5.3). According

¹ This document is over 20 pages long and, in accordance with paragraph 6.11 of the Committees' Guidelines (MSC-MEPC.1/Circ.4/Rev.2), only the first three pages will be translated into the three working languages, with the annex in English only.

to section 6 of Procedure (G9), the Organization should evaluate the information provided in the application.

3 According to BWM.2/Circ.38/Rev.1, proposals for approval of ballast water management systems that make use of Active Substances are to be submitted to the Marine Environment Division of the Organization to be reviewed by the GESAMP-Ballast Water Working Group. In the meantime, a document on the proposal for approval containing all the non-confidential data related to the respective ballast water management systems that make use of Active Substances is to be submitted to MEPC 65.

4 Based on the definitions contained in the updated Methodology for information gathering and conduct of work of the GESAMP-BWWG (BWM.2/Circ.13/Rev.1), this document is written for approval of ballast water management systems that make use of Active Substances.

5 The competent authority in the Republic of Korea has verified the application dossier prepared by SUNBO INDUSTRIES Co. Ltd., DSEC Co. Ltd., and the Korean Institute of Machinery and Material (KIMM) and believes it satisfies the data requirements of Procedure (G9) adopted by resolution MEPC.169 (57).

6 Therefore, the Republic of Korea submits the non-confidential part of the applicant's dossier in the annex to this document to the Organization for evaluation according to Procedure (G9). The complete dossier will be made available to the experts of the GESAMP-BWWG with the understanding of confidential treatment.

Summary of non-confidential information on the Blue Zone™ BWMS

7 Ozone (O₃) is defined as Active Substance in the Blue Zone™ Ballast Water Management System (BWMS)

8 The Blue Zone™ BWMS is designed by SUNBO Industries Co., Ltd. This system consists of an ozone generation module, a mainstream ozone micro bubble module, a neutralization module and a monitoring and control module. This system has a two-step treatment:

- .1 **Disinfection step** – with in situ micro-sized ozone bubbles generated by a bubble nozzle during the ballasting process. The disinfection of the ozone bubbles follows the next steps:
 - The ozone gas is injected in the form of micro-sized bubbles into the main ballasting pipe using a micro bubble nozzle.
 - The ozone bubbles react with the bromine ions in the seawater to generate TRO during ballasting.
- .2 **Neutralization step** – thiosulfate solution is added into the treated ballast water during de-ballasting process to neutralize the TRO:
 - The injection rate of thiosulfate solution is automatically controlled.

9 During the ballasting process, the micro-sized ozone bubbles enlarge the contact surface between the seawater and ozone gas, and are more efficient in eliminating aquatic organisms in the treated water compared to larger ozone bubbles. The ozone gas in ballast water was injected with maximum amount of 2.32 mg/L TRO as Cl₂ (maximum dose).

The TRO was automatically controlled by the human machine interface (HMI) and the programmable logic controller (PLC). To control the maximum TRO less than 2.32 mg/L as Cl₂ automatically, the parameters should be input to the PLC by the operator.

10 Neutralizing agents, thiosulfate solution is injected into the de-ballasting pipe to neutralize the remaining TRO during de-ballasting process. The injection rate of thiosulfate solution is controlled to be below the Maximum Allowable Discharge Concentration (MADC), 0.2 mg/L TRO as Cl₂.

11 The results of the biological efficacy test show that the Blue Zone™ BWMS satisfies the performance standards of regulation D-2 of the BWM Convention. The results of the chemical and aquatic ecotoxicity tests in accordance with Procedure (G9) are reported in the application dossier.

12 The predicted environmental concentrations (PEC) of disinfection by-products (DBP) were calculated using the MAMPEC-BW Model 3.0 exposure model. The predicted no effect concentrations (PNEC) were derived from the available information on acute and chronic aquatic toxicity. The environmental risk quotient for DBP in the treated discharge water was mostly far below 1, indicating negligible risk even though the PEC applied in the risk assessment were the maximum concentrations predicted by MAMPEC-BW Model 3.0.

13 The health risks of Relevant Chemicals posed by the Blue Zone™ BWMS are assessed under various exposure scenarios. The treatment by the system has negligible adverse effects upon inhalation, dermal, and/or oral exposure route. It was demonstrated that a proper operation and an appropriate response to the present system assures the safe operation of ships and the safety for both the ship's crew and public population (sections 7.2.4).

14 In conclusion, the risk assessments show that operation of the Blue Zone™ BWMS will not cause adverse effects on the aquatic organisms or human health.

Action requested of the Committee

15 The Committee is invited to consider the proposal for Basic Approval and decide as appropriate.

Note:

In accordance with the decision of MEPC 63 (MEPC 63/23, paragraph 2.18), only the cover note is printed and distributed in hard copy. The full document (cover note and annex) is available electronically through IMODOCS.

ANNEX

NON-CONFIDENTIAL INFORMATION ON THE Blue Zone™ BALLAST WATER MANAGEMENT SYSTEM

Table of Contents

1 INTRODUCTION

- 1.1 Brief History of the Blue Zone™ BWMS
- 1.2 Abbreviations used in the text

2 OVERVIEW OF THE TEST SCHEME

- 2.1 Observance of the regulation
- 2.2 Principles of acceptability of BWMS that make Use of Active Substances
- 2.3 Submission of an application for Basic Approval
- 2.4 Confidentiality and data protection
- 2.5 Test methods
- 2.6 Quality control and assurance ((G9): 4.2.4)

3 APPLICATION DATA-SET

- 3.1 Description of the Blue Zone™ BWMS
- 3.2 Introduction of application data
- 3.3 Identification of the substances or Preparation ((G9): 2.4.1)
- 3.4 Data on the efficacy of organism removal from natural seawater (G8)
- 3.5 Data on effects on aquatic plants, invertebrates and fish, and other biota, including sensitive and representative organisms ((G9): 4.2.1.1)
- 3.6 Data on mammalian toxicity ((G9): 4.2.1.2)
- 3.7 Data on environmental fate and effect under aerobic and anaerobic conditions ((G9): 4.2.1.3)
- 3.8 Physical and Chemical Properties for the Active Substances, Relevant Chemicals and Treated Ballast Water ((G9): 4.2.1.4)
- 3.9 Analytical methods at environmentally Relevant Concentrations ((G9): 4.2.1.5)

4 THE USE OF ACTIVE SUBSTANCE ((G9): 4.2.6)

- 4.1 The Manner of Application

5 RISK CHARACTERIZATION-HUMAN HEALTH

- 5.1 Hazard identification
- 5.2 Exposure assessment
- 5.3 Effect assessment
- 5.4 Risk characterization

6 RISK CHARACTERIZATION - ENVIRONMENT

- 6.1 Screening for persistence, bioaccumulation, and toxicity ((G9): 5.1)
- 6.2 Evaluation of the treated ballast water ((G9): 5.2)
- 6.3 Risk characterization and analysis

7 RISK ASSESMENT

- 7.1 Risk to safety of ship
- 7.2 Risk to human health
- 7.3 Risk to aquatic environment

8 ASSESSMENT REPORT

APPENDIES (provided in confidential application dossier)

APPENDIX I	KEY DATA SUMMARY
APPENDIX II	QMP AND QAPP FOR Blue Zone™ BWMS OZONE SYSTEM
APPENDIX III	QAPP FOR BIOLOGICAL EFFICACY TEST AND TEST REPORT
APPENDIX IV	QAPP FOR CHEMICAL ANALYSIS AND TEST REPORTS
APPENDIX V	QAPP FOR AQUATIC TOXICITY TEST AND TEST REPORTS
APPENDIX VI	REFERENCE ECOTOXICITY DATA FROM LITERATURE
APPENDIX VII	HUMAN RISK ASSESSMENT OF BALLAST WATER CHEMICALS
APPENDIX VIII	PEC USING MAMPEC BW 3.0 MODEL
APPENDIX IX	SYSTEM DESCRIPTION OF Blue Zone™ BWMS
APPENDIX X	THE RESULTS OF TRO MONITORING
APPENDIX XI	MATERIAL SAFETY DATA SHEET
APPENDIX XII	OPERATION AND SAFETY
APPENDIX XIII	COMPONENT MANUALS
APPENDIX XIV	APPLICATION OF INSTALLATION AND ARRANGEMENT
APPENDIX XV	REFERENCES

1 INTRODUCTION

This document contains the non-confidential application dossier for Basic Approval for the GESAMP-BWWG to evaluate in accordance with the *Procedure for approval of ballast water management systems that make use of Active Substances (G9)*, as revised (adopted by resolution MEPC.169(57)).

1.1 Brief history of the Blue Zone™ BWMS

SUNBO INDUSTRIES Co. Ltd., DSEC Co. Ltd. and the Korea Institute of Machinery & Material (KIMM) have jointly developed the Blue Zone™ Ballast Water Management System (BWMS) with the support of the Korean National Research and Development Program of Daedeok Innopolis.

SUNBO has been one of major companies in the Republic of Korea to fabricate and assemble the structural and outfitting components for the shipbuilding industry since 1986, and has held a leading position in the development of the Blue Zone™ BWMS.

DSEC is a total ship and marine engineering company handling design, procurement, inspection and logistics since 2002.

KIMM has conducted research on core technology (micro-size ozone bubble generation) in environmental machinery, with the aim of enabling the development of green technology.

The laboratory test facility for the development of the Blue Zone™ BWMS was provided at the seaside premises of SUNBO UNITECH (a subsidiary of SUNBO INDUSTRIES) located in Busan, Republic of Korea

The laboratory scale test was performed from June to July 2012 for IMO Basic Approval.

The biological efficacy test, aquatic eco-toxicity test, chemical analysis for identification of disinfection by-products (DBP's), and risk assessment were performed and evaluated by the Korean Institute of Ocean Science and Technology, (KIOST, formerly KORDI), NeoEnBiz Co. and Lab Frontier Co. Ltd.

The results of the biological efficacy, chemical and toxicity tests show that the Blue Zone™ BWMS complies with the standard described in regulation D-2 of the Convention and Procedure (G9).

1.2 Abbreviations used in the text

ABBREVIATIONS

ADD	Average Daily Dose
AS	Active Substance
ASTM	American Society for Testing of Materials
BA	Basic Approval
BCF	Bioconcentration Factor
BWMS	Ballast Water Management System
CAS	Chemical Abstracts Service
CV	Coefficient of Variation
DNEL	Derived No-Effect Level
DOC	Dissolved Organic Carbon
EC ₅₀	Effect Concentration, 50% (median effective concentration)
GLP	Good Laboratory Practice

HMI	Human Machine Interface
ISO	International Organization for Standardization
K_{oc}	Organic carbon-water partition coefficient
K_{ow}	Octanol/water partitioning coefficient (also P_{ow})
K_p	Sorption coefficient for ionic substances
LC ₅₀	Lethal Concentration, 50%
LD	Lethal Dose, 50%
LOAEL	Lowest Observed Adverse Effect Level
LOEL	Lowest Observed Effect Level
Log P_{ow}	Logarithm of the octanol/water partition coefficient
MADC	Maximum Allowable Discharge Concentration
MAMPEC-BW	Marine Antifoulant Model for PEC calculation for Ballast Water
MD	Maximum Dose
MOMB	Mainstream Ozone Micro Bubble
NOAEC	No Observed Adverse Effect Concentration
NOEC	No Effect Concentration
NOAEL	No-Observed-Adverse-Effect Level
NOEL	No-Observed-Effect Level
OECD	Organization for Economic Co-operation and Development
PBT	Persistence, Bioaccumulation and Toxicity
PEC	Predicted Environmental Concentration
PLC	Programmable Logic Controller
PNEC	Predicted No Effect Concentration
POC	Particulate organic carbon
P_{ow}	Octanol/water partition coefficient (also K_{ow})
PPE	Protective Personal Equipment
QAPP	Quality Assurance Project Plan
QA/QC	Quality Assurance/Quality Control
RC	Relevant Chemical
RCR	Risk Characterization Ratio
TOC	Total Organic Carbon
TRO	Total Residual Oxidant
US EPA	United States Environmental Protection Agency
WET	Whole Effluent Toxicity

2 OVERVIEW OF THE TEST SCHEME

2.1 Observance of the regulation

The legal provision for this application is regulation D-3.2 of the International Convention for the Control and Management of Ships' Ballast Water and Sediments, 2004, which stipulates that ballast water management systems that make use of Active Substances shall be approved by the Organization. During its fifty-third session, the Marine Environment Protection Committee (MEPC) adopted the *Procedure for approval of Ballast Water Management Systems that make use of Active Substances (G9)* through resolution MEPC.126(53). The revised Procedure (G9) was adopted by resolution MEPC.169(57). This application and the comprehensive testing program that has been conducted by SUNBO Industries Co. Ltd. to support it are in full compliance with Procedure (G9).

2.2 Principles of acceptability of BWMS that make use of Active Substances

In accordance with Procedure (G9) and as presented in this report, SUNBO Industries Co. Ltd. has sought to meet the principles of acceptability by undertaking comprehensive toxicity testing of ballast water treated with the Blue Zone™ in system testing, in order to determine if the system can be used and under which conditions the potential for harming the receiving environment or human health is acceptably low.

2.3 Submission of an application for Basic Approval

This application is for Basic Approval. The information in this dossier includes:

- Result of the comprehensive Procedure (G9) toxicity testing and chemical analysis;
- Result of the Guidelines (G8) efficacy testing;
- Quality Assurance Project Plan (QAPP); and
- Technical specifications of the optimized Blue Zone™ BWMS.

2.4 Confidentiality and data protection

All information contained in this application and supporting documents are to be considered as confidential, except the information that is included in the non-confidential summary document. SUNBO Industries Co. Ltd. accepts that all items listed in section 2.4 of the Methodology for information gathering and conduct of work of the GESAMP-BWWG (BWM.2/Circ.13/Rev.1) shall not be regarded as confidential once the system and Active Substance are approved.

2.5 Test methods

The undertaking of comprehensive testing for efficacy and toxicity of the Blue Zone™ BWMS comprises four major tasks:

- .1 Sampling;
- .2 Determination of water quality parameters and efficacy testing of the samples (Guidelines (G8) testing);
- .3 Chemical analysis of the samples (Procedure (G9) testing); and
- .4 Whole Effluent Toxicity (WET) testing of the samples (Procedure (G9) testing).

The quality assurance arrangements for the tasks are the subject of a QAPP developed by SUNBO Industries Co. Ltd. and KIOST (formerly KORDI). All test methods were carried out in compliance with the requirements of the Guidelines (G8) and Procedure (G9).

2.5.1 Sampling

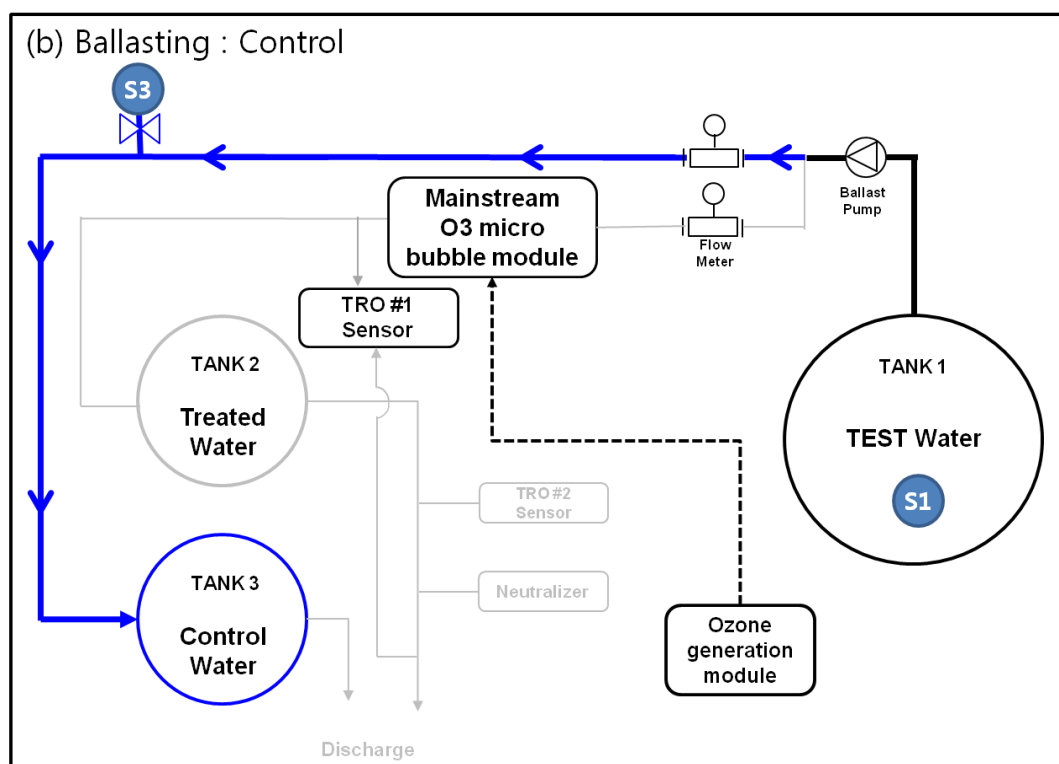
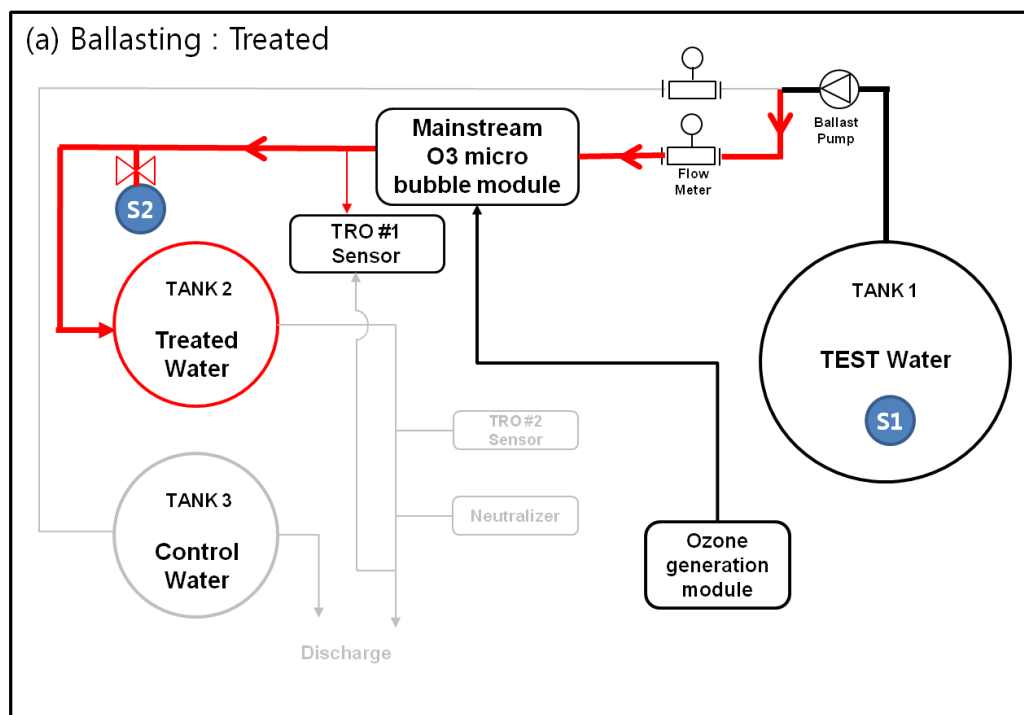
Two types of water (seawater and brackish water) were used for all tests in this dossier. Test water was taken from ~50 m outward from the shore. Brief information of the laboratory scale test facility is given in Table 2.1.

Table 2.1: The Information of the laboratory scale test

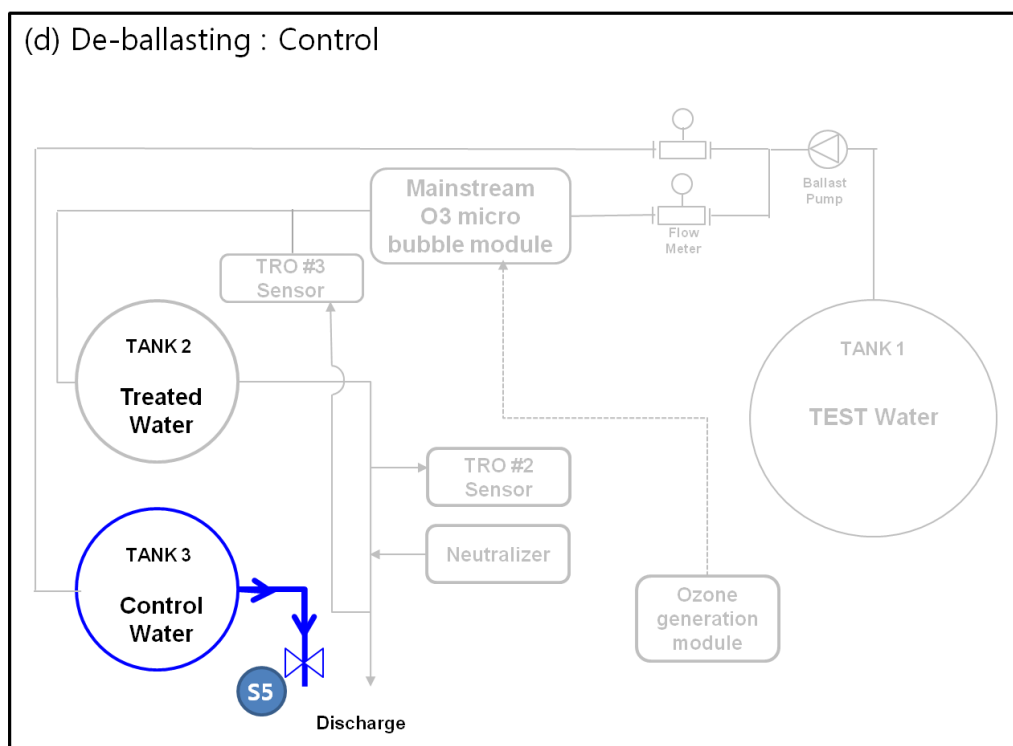
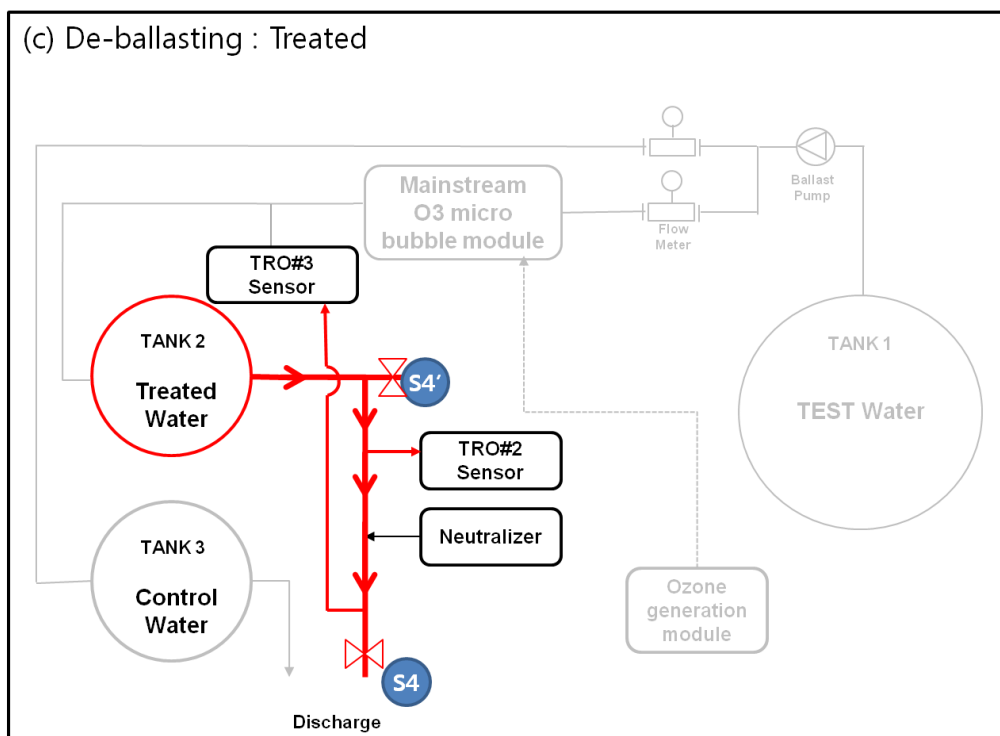
	Seawater	Brackish water
Test date	- Ballasting : 2012/06/13 - De-ballasting : 2012/06/18	- Ballasting : 2012/07/04 -De-ballasting: 2012/07/09
Salinity	32 PSU	21 PSU
Ballast flow rate	5.0 m ³ /h - pumping	
De-ballast flow rate	4.3 m ³ /h - gravity	
Test water volume	10.0 m ³	
Treated volume	Control water: 5.0 m ³ Treated water: 5.0 m ³	
Treatment capacity	5.0 m ³ /hr of ballast water	
Maximum TRO concentration in ballasting line	2.32 mg/L TRO as Cl ₂	

The flow diagram of the test facility is shown in Figure 2.1. The facility has three tanks and one ballast pump to simulate the ballasting and de-ballasting process.

Sampling points are indicated by S1-S5 in Figure 2.1. The grab sample for performance analysis (biological efficacy test) was collected in triplicates at the beginning, middle, and end of ballasting and de-ballasting mode respectively. The samples for chemical analysis and aquatic ecotoxicity test were collected just one time at middle of performance analysis sampling during ballasting and de-ballasting respectively.



(a) Water flow during ballasting in the laboratory scale test



(b) Water flow during de-ballasting in the laboratory scale test

Figure 2.1: Test water flow diagram and sampling points

Table 2.2: Sampling information for laboratory scale test of the Blue Zone™ BWMS

Sampling for		Sample ID (Sampling Location)		On-site measurement	Off-site measurement	Salinity
		Treated water	Control water			
Aquatic toxicity test	Day 0 : ballasting	S-Treated (D0) B-Treated (D0) (S2)	S-Control (D0) B-Control (D0) (S3)		- Bacteria - Algae - Rotifer - Amphipod - Fish	- 32 PSU - 21 PSU
	Day 5 : de-ballasting	Before and After neutralization of S-Treated (D5) B-Treated (D5) (S4', S4)	S-Control (D5) B-Control (D5) (S5)			
Chemical analysis	Day 0 : ballasting	S-Treated (D0) B-Treated (D0) (S2)	S-Control (D0) B-Control (D0) (S3)	- TRO Conc.	- Relevant Chemicals	
	Day 5 : de-ballasting	Before and After neutralization of S-Treated (D5) B-Treated (D5) (S4', S4)	S-Control (D5) B-Control (D5) (S5)			
Biological efficacy test	Test water	Test water (S1)		- Organisms: ≥ 50 µm, ≥ 10-50 µm - Temp. - Salinity - DO - pH - NTU	- Bacteria - DOC - TOC - TSS	
	Day 0 : ballasting	S-Treated (D0) B-Treated (D0) (S2)	S-Control (D0) B-Control (D0) (S3)			
	Day 5 : de-ballasting	S-Treated (D5) B-Treated (D5) (S4)	S-Control (D5) B-Control (D5) (S5)			

Detailed description for each sample in Table 2.2 and Figure 2.1 are as follows:

- S1, Test water (IMO soup) at day 0
- S2, Treated water during ballasting at day 0
- S3, Control water during ballasting at day 0
- S4', Treated water during de-ballasting at day 5, treated water before neutralization process sampled from the tank directly.
- S4, Treated water during de-ballasting after neutralization at day 5
- S5, Control water during de-ballasting at day 5

Collection of field samples was undertaken by marine biologists and environmental engineers from KIOST and NeoEnBiz Co., using standard water sample collection methods and in accordance with the Guidelines (G8). Standard operating procedures (SOPs) were employed to provide consistency and reproducibility of the sampling methods used by field personnel, as outlined in the Quality Assurance Project Plan (QAPP).

Water samples were taken from both the control (untreated) and treatment at two intervals following treatment – at the ballasting (immediately after treatment, day 0), and at five days after treatment with neutralization. An overview of the sampling points is presented in Figure 2.1.

2.5.2 Efficacy testing

Assurance of fulfilment of water quality test criteria and bio-efficacy testing was conducted by KIOST, based on the quality system of ISO/IEC 17025, in accordance with the IMO Guidelines (G8). Full details are contained in the QAPP.

2.5.3 Chemical analysis

At each sampling event Active Substance (TRO as Cl_2) was measured immediately on site, and the samples were then sent to the laboratory of LabFrontier Co. LTD. for analysis of Relevant Chemicals (DBPs).

The analytical laboratory services for the measurement of DBPs using the discharge water samples from the Blue Zone™ BWMS were carried out by qualified and accredited laboratories under internationally recognized guidelines (OECD or equivalent) and quality system of ISO/IEC 17025. Full details are contained in the QAPP.

2.5.3 Whole effluent toxicity (WET) testing

WET testing was carried out by NeoEnbiz Co., under internationally recognized guidelines (OECD or equivalent) and on international quality assurance system (GLP). This testing aims to assess the residual toxicity of whole effluent ballast water after treatment by the Blue Zone™ BWMS, in accordance with the Procedure (G9).

In accordance with the Procedure (G9), a number of different tests were required as listed below:

- Luminescence Inhibition Test with bacteria;
- Population Growth Inhibition Test with microalgae ;
- Survival Test with rotifer and amphipod (invertebrates); and
- Survival Test with fish (vertebrates).

2.6 Quality Control and Assurance ((G9): 4.2.4)

Quality Control and Assurance (QA/QC) are of primary importance. The essential goal is to deliver reliable analytic results of defined quality. All testing processes in analytical laboratories contain a rigorous quality control/quality assurance program consisting of a Quality Management Plan (QMP) and a Quality Assurance Project Plan (QAPP) as set out in appendix II.

All analyses were carried out in accordance with standard methods, and aquatic ecotoxicity testing was performed under supervision of the KIOST (formerly KORDI), LabFrontier (LF) Co. Ltd. and NeoEnBiz Co. (NEB). The KIOST laboratory is accredited by the Korean Laboratory Accreditation Scheme (KOLAS) for phytoplankton and micro-organism analyses. The KIOST study director is accredited by IOC-UNESCO for identification of harmful microalgae (appendix III). The LF laboratory is accredited by KOLAS for chemical analysis of environmental samples (appendix IV). Although the NeoEnBiz institute is not accredited specifically for toxicological testing, the institute has an ecotoxicology laboratory, personnel

with solid experience in toxicological research funded by various agencies including the government of the Republic of Korea (e.g. Ministry of Land, Transport and Maritime Affairs), and all WET tests were performed according to GLP. The data on quality assurance (QA) are provided for each test report. (appendix V).

3 APPLICATION DATA-SET

3.1 Description of the Blue Zone™ BWMS

The Blue Zone™ BWMS is a system that disinfects all harmful aquatic organisms and pathogens in ballast water of ships using micro-sized ozone bubbles.

The Blue Zone™ BWMS consists of the following modules:

- .1 Ozone generation module;
- .2 Mainstream ozone micro bubble module (MOMB module) (Ozone bubble generation device and collision and mixing device);
- .3 Neutralization module; and
- .4 Monitoring and control module.

Figure 3.1 shows the schematic process diagram of the Blue Zone™ BWMS

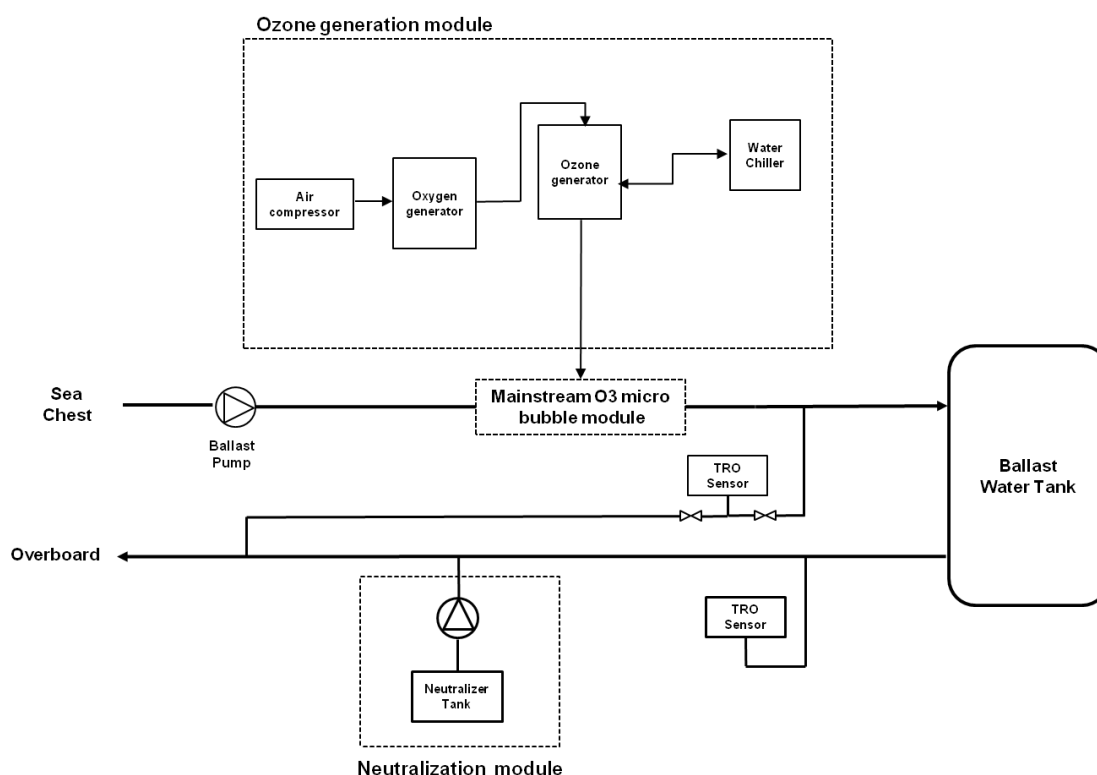


Fig. 3.1: Schematic process diagram of the Blue Zone™ BWMS

The TRO was automatically controlled by human machine interface (HMI) and programmable logic controller (PLC). To control the maximum TRO less than 2.32 mg/L as Cl₂ automatically, parameters should be input to the PLC by the operator.

3.1.1 System working principles

In the Blue Zone™ BWMS, the air compressor compresses the atmospheric air and discharges compressed air into the oxygen generator. With removing nitrogen from the compressed air inside of the oxygen generator, purified oxygen is produced. The purified oxygen then passes through the ozone generator to produce the ozone. The produced ozone is injected into the ballast water through the micro-bubble nozzle to disinfect aquatic organisms. When the ozone reacts with bromide ion in ballast water, the TRO composed of hypobromous acid (HOBr) and hypobromite ion (OBr⁻) is produced.

The Active Substance of the Blue Zone™ BWMS is ozone. The ozone dose determined by O₃ produced (g/hr) and ballast flow rate (m³/hr) is measured with sensors.

The chemical reactions of ozonation

In seawater, the primary reactions of ozone are as follows:

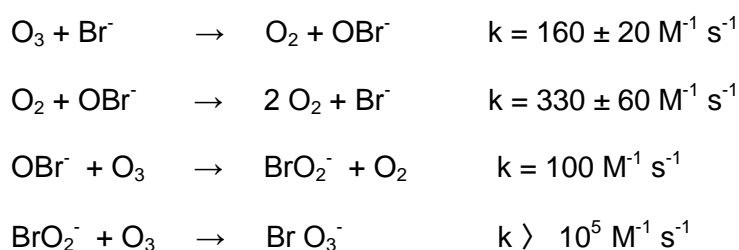


Figure 3.2 shows the primary reaction of the ozone and bromide ions in the seawater.

HOBr and OBr⁻ form the equilibrium in a quick reaction with the ozone.

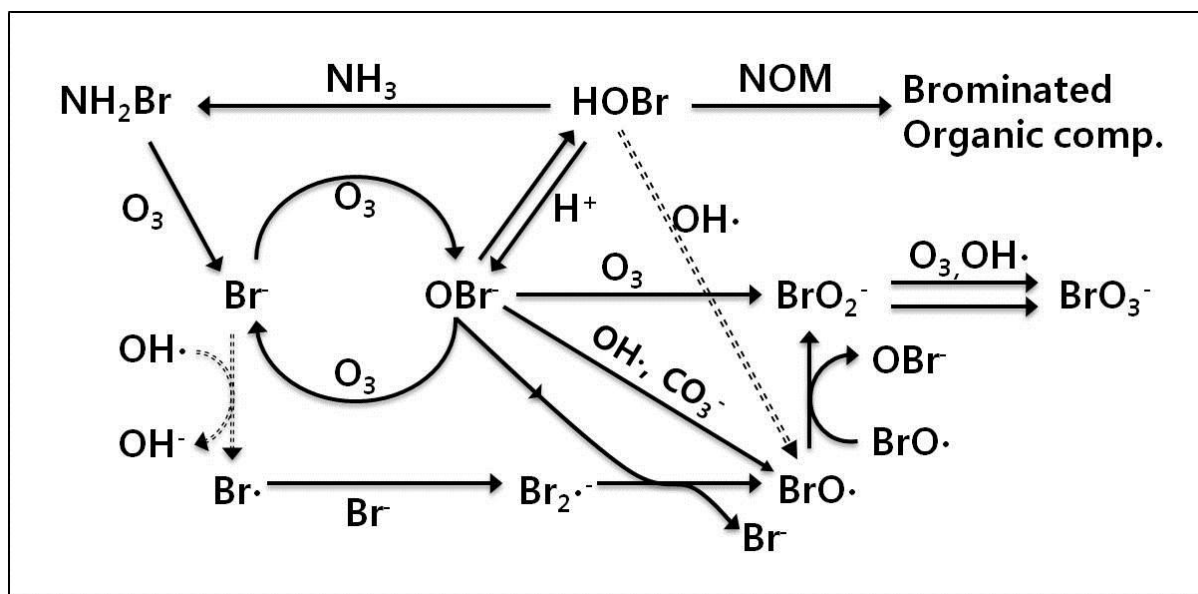
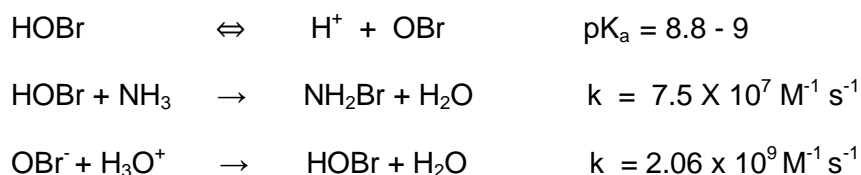


Figure 3.2: Primary reaction of ozone and bromide ion in seawater

The primary reactions of HOBr and OBr were as follows:

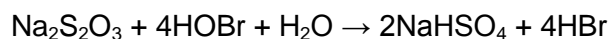
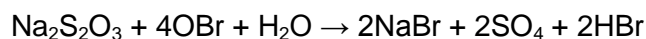
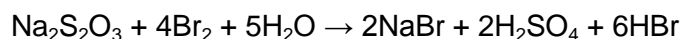


The chemical reactions of neutralization

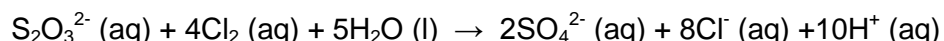
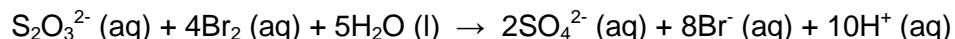
The TRO remaining in the ballast tank is neutralized by the thiosulfate solution during the de-ballasting process.

Thiosulfate solution has multiple reactions with chlorine or bromine species. It is an effective means (mechanism) for the removal of any combined chlorine or bromine species such as chloramines or bromamine. The chemical reactions are shown below:

Sodium thiosulfate:



Thiosulfate ion:



The theoretical dose ratio of bromine and thiosulfate solution, according to stoichiometry, is 0.18 (112 as $\text{S}_2\text{O}_3^{2-}$ / 4 x 158 as Br_2). Theoretical dosing rate of 0.18 was not sufficient to neutralize TRO below 0.2 mg/L TRO as Cl_2 . Considering the water conditions and initial TRO level, the required dosing rates to maintain the concentration of TRO were determined to 0.44 by considering the end point of the neutralization.

The added thiosulfate solution is approved to chemically reduce any residual oxidants and is expected to be in the form of thiosulfate ion ($\text{S}_2\text{O}_3^{2-}$).

The commercial neutralizing agents were used for the laboratory scale test. 500 g of sodium thiosulfate and distilled water are used for 1 L volume of the solution.

3.1.2 Ozone generation module

Ozone can be produced in several ways. Among the various methods corona discharge is the most widely used method in the ozone production industry. The commercial ozone generator used in the laboratory scale test for Basic Approval of the Blue Zone™ BWMS was a medium frequency and silent corona discharge type of generator.

3.1.3 Mainstream O₃ micro-bubble module (MOMB module)

The MOMB module consists of the ozone bubble generation device and the collision and mixing device. In the ozone bubble generation device, to produce micro-sized ozone bubbles the ozone is injected by the micro-bubble nozzle and water pump.

In the collision and mixing device, the micro sized ozone bubbles spread into and mix it with seawater. The aquatic organisms can be injured by a collision in this device.

3.1.4 Neutralization module

The neutralization module consists of the neutralizer storage tank (SUS 304), metering pump (chemical dosing pump), and an injection nozzle equipped with a back pressure valve. Neutralizing agent is injected directly into the ballasting water via pipe and metering pump. Thiosulfate solution is used as the neutralizing agent. The neutralization module of the Blue Zone™ BWMS is designed to maintain the TRO value of less than the MADC, 0.2mg/L as Cl₂ in the ballast water to be discharged.

In the beginning of the de-ballasting process, the module overdoses the neutralizer until TRO monitoring and measuring reach a steady state. After all conditions are stable, the calculated volume of neutralizer corresponding with the value of TRO is injected.

Table 3.2 presents examples of the required neutralizer flow rate during 5 days TRO degradation.

Table 3.2: The theoretical required volume of neutralizing agents in seawater test

	TRO in treated ballast <i>pipe</i>	TRO in treated ballast <i>tank</i>					
	D0	D0	D1	D2	D3	D4	D5 (*B.N)
TRO (mg/L as Cl ₂)	2.32	1.93	0.81	0.50	0.32	0.18	0.05
Required neutralizer (g/hr)	4.39	3.65	1.53	0.95	0.61	0.34	0.09
Flow rate of required neutralizer (mL/min)	0.15	0.12	0.05	0.03	0.02	0.01	0.00

* B.N=Before Neutralization

- .1 Required neutralizer (g/hr) = de-ballasting flow rate (m³/hr) x TRO (g/m³) x neutralizer dose
- .2 Flow rate of required neutralizer (L/hr) = required neutralizer (g/hr) /neutralizer concentration (g/L)
- .3 Neutralizer concentration (g/L) = 500 g/L as S₂O₃²⁻

In the laboratory scale test, the concentrations of thiosulfate solution after neutralization were analysed as 246.82 mg/L (brackish water) and as 186.48 mg/L (seawater) in the treated water.

Table 3.2 shows that the TRO is less than 0.2 mg/L during the de-ballasting process. According to the data requirements of Procedure (G9), however, the injection of neutralizer was conducted obligatorily.

3.1.5 Monitoring and control module

The monitoring and control of the Blue Zone™ BWMS in the laboratory scale test is executed by the HMI and PLC (Model as LS XGP-AC23).

The data acquired from each measuring instrument can be used as a communicator between each measuring instrument and a personal computer using the RS-232.

All measurements and control values are continuously recorded in the "OPERATION REPORT" contained in appendix X in real time during the operation.

3.2 Introduction of application data

This dossier contains the information specified in Procedure (G9). For Active Substances and/or Preparations including any of its components as appropriate, data on properties is included. For Relevant Chemicals (RCs), data is provided as well. Literature review and testing on fate and effect were performed with the laboratory scale test with Active Substances and Preparations (G9: 5.3.1). Any reference to specific test methods in the following is indicative with the purpose of providing guidance to an Administration on possible methods that were considered. Any other internationally recognized test methods were used as well.

3.3 Identification of the Active Substances or Preparation ((G9):4.1)

3.3.1 Preparations

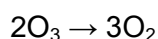
"Preparation" means any commercial formulation containing one or more Active Substances including any additives.

As outlined above, the Blue Zone™ BWMS does not involve the formulation of any Preparation to be carried on-board the ship for use in the BWMS. Instead, the Active Substance as ozone is generated on-board as required.

Strictly speaking then, the micro-ozone bubble is the Active Substance of relevance to the Blue Zone™ BWMS. The by-products of ozone are collectively referred to as disinfection by-products (DBPs), and may be considered as Relevant Chemicals. However, as stated above, for the purposes of this application and the whole effluent testing that has been conducted to support it, "Preparation", "Active Substance" and "Relevant Chemicals", as well as "Ballast Water Discharge", all have the same meaning. This "Whole Effluent" approach has been adopted for other oxidant-based BWMS that have been granted Final Approval by MEPC. Nevertheless, relevant data as required by Procedure (G9) are provided below for Active Substance and Relevant Chemicals.

3.3.2 Active Substance

Ozone is defined as "Active Substance (AS)" in the Blue Zone™ BWMS. Ozone is a molecule that consists of three negatively charged oxygen atoms. The ozone molecule is very unstable and has a short half-life, causing it to fall back into its original form after a while, according to the following reaction mechanism:



Ozone generators can create ozone artificially by means of extremely high voltages, as used here. Ozone is a powerful oxidant able to achieve disinfection with less contact time and

concentration than all weaker disinfectants, such as chlorine, chlorine dioxide, and monochloramine (Demers and Renner, 1992).

Table 3.3: Identification of Active Substance

Chemicals	CAS No.	Molecular weight	Chemical formula
Ozone	10028-15-6	47.98	O ₃

Total residual oxidant (TRO) was monitored instead of the concentration of ozone in treated water, which was used to control the injection concentration of ozone into the ballasting line. TRO was measured *in situ* by CLX on-line (HF Scientific, USA), which applied ISO 73932(1985)/APHA Standard methods for the Examination of Water and Wastewater (21st Edition, 2005), Method 4500-Cl G DPD Colorimetric Method. In the analyses of the treated water, the concentrations of TRO are given as Cl₂. Also, TRO measurement was internally performed with a standard DPD colorimetric method (US EPA Method 330.5) with other chemical analysis.

3.3.3 Relevant Chemicals ((G9): 2.1.4)

During the process of disinfection using ozone generation module, disinfection by-products (DBPs) such as oxyhalide anions, trihalomethanes (THMs), haloacetic acids (HAAs), haloacetonitriles (HANs) and other halogenated chemicals can be produced by the reaction of TROs with organic matters. These DBP chemicals are classified as "Relevant Chemicals" (RC). Thiosulfate solution which is used in the neutralizing process in this system is also included in RCs (Table 3.4).

Table 3.4: Identification of Relevant Chemicals

Chemicals	CAS No.	Molecular weight	Chemical formula
Oxyhalide anions			
Bromate	15541-45-4	127.90	BrO ₃ ⁻
Chlorate	14866-68-3	83.45	ClO ₃ ⁻
Perchlorate	14797-73-0	99.45	ClO ₄ ⁻
THMs (Trihalomethanes)			
Dibromochloromethane	124-48-1	208.29	CHBr ₂ Cl
Dichlorobromomethane	75-27-4	163.80	CHBrCl ₂
Tribromomethane (bromoform)	75-25-2	252.77	CHBr ₃
Trichloromethane (chloroform)	67-66-3	119.38	CHCl ₃
HAAs (Haloacetic acids)			
Monochloroacetic acid	79-11-8	94.50	C ₂ H ₃ ClO ₂
Dichloroacetic acid	79-43-6	128.90	CHCl ₂ COOH
Trichloroacetic acid	76-03-9	163.40	CCl ₃ COOH
Monobromoacetic acid	79-08-3	138.95	C ₂ H ₃ BrO ₂
Dibromoacetic acid	631-64-1	217.84	Br ₂ CHCOOH
Tribromoacetic acid	75-96-7	296.74	C ₂ HBr ₃ O ₂
Bromochloroacetic acid	5589-96-8	173.39	C ₂ H ₂ BrClO ₂
Dibromochloroacetic acid	5278-95-5	252.29	C ₂ HBr ₂ ClO ₂
Dichlorobromoacetic acid	71133-14-7	207.84	C ₂ HBrCl ₂ O ₂
HANs (Haloacetonitriles)			
Chloropicrin	76-06-2	164.38	CCl ₃ NO ₂
Monobromoacetonitrile	590-17-0	119.95	C ₂ H ₂ BrN
Dibromoacetonitrile	3252-43-5	198.84	Br ₂ CHCN

Chemicals	CAS No.	Molecular weight	Chemical formula
Other halogenated chemicals			
2,4,6-Tribromophenol	118-79-6	330.80	C ₆ H ₃ Br ₃ O
1,2,3-Trichloropropane	96-18-4	147.43	C ₃ H ₅ Cl ₃
Neutralizer			
Sodium thiosulfate	7772-98-7	158.11	Na ₂ S ₂ O ₃

Different sample types (control and treated water under seawater and brackish water conditions at day 0 and day 5, and especially at day 5 before and after neutralization) were evaluated for DBPs as Relevant Chemicals. As a reference, a water sample before neutralization at day 5 was included in the chemical analysis. The data is presented in Table 3.5.

The concentration of thiosulfate solution as the neutralizer is relatively higher at day 5 after the neutralization process on both seawater and brackish water since excessive neutralizer was consumed for removing TRO in de-ballasting treated water. Even though the control of neutralization process by the Blue Zone™ BWMS is designed to operate automatically, the system did not work when the concentration of TRO as Cl₂ in de-ballasting treated water was extremely low, < 0.02 mg/L TRO as Cl₂. Owing to the malfunction caused by the experimentalist, the concentration of the thiosulfate was extremely high on day 5.

Table 3.5: The concentration of Relevant Chemicals of the Blue Zone™ BWMS

Name of chemical substance	Unit	aMDL	Elapsed time (day) and concentration				
			Day 0		Day 5		
			Control water	Treated water	Control water	bTreated water	
						Before N	After N
Seawater (32 PSU)							
Oxyhalide anions							
Bromate	µg/L	1.34	3.28	30.83	3.79	32.87	31.96
Chlorate	mg/L	0.17	< 0.17	< 0.17	< 0.17	< 0.17	< 0.17
Perchlorate	µg/L	0.40	0.53	0.50	0.49	0.46	0.86
Trihalomethanes							
Dibromochloromethane	µg/L	1.65	3.22	2.30	< 1.65	4.59	4.45
Dichlorobromomethane	µg/L	1.24	6.54	4.62	2.16	2.55	3.17
Bromoform	µg/L	1.75	4.09	16.35	4.23	107.63	96.2
Chloroform	µg/L	1.34	7.94	6.07	3.97	4.35	4.83
Haloacetic acids							
Monochloroacetic acid	µg/L	0.10	< 0.10	< 0.10	< 0.10	< 0.10	< 0.10
Dichloroacetic acid	µg/L	0.06	0.41	0.38	< 0.06	0.44	< 0.06
Trichloroacetic acid	µg/L	0.07	< 0.07	< 0.07	< 0.07	< 0.07	< 0.07
Monobromoacetic acid	µg/L	0.09	< 0.09	0.48	< 0.09	< 0.09	< 0.09
Dibromoacetic acid	µg/L	0.06	< 0.06	9.42	< 0.06	9.81	6.15
Tribromoacetic acid	µg/L	0.05	< 0.05	0.61	< 0.05	2.96	< 0.05
Bromochloroacetic acid	µg/L	0.06	< 0.06	1.01	< 0.06	0.46	0.26
Dibromochloroacetic acid	µg/L	0.10	< 0.10	< 0.10	< 0.1	< 0.10	< 0.10

Name of chemical	Unit	^a MDL	Elapsed time (day) and concentration				
Dichlorobromoacetic acid	µg/L	0.06	< 0.06	< 0.06	< 0.06	0.26	< 0.06
Haloacetonitriles							
Chloropicrin	µg/L	0.02	1.05	1.04	1.15	1.23	1.42
Monobromoacetonitrile	µg/L	0.03	< 0.03	1.6	< 0.03	< 0.03	< 0.03
Dibromoacetonitrile	µg/L	0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02
Other halogenated chemicals							
2,4,6-Tribromophenol	mg/L	0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
1,2,3-Trichloropropane	µg/L	1.32	< 1.32	< 1.32	< 1.32	< 1.32	< 1.32
Thiosulfate	mg/L	0.50	< 0.50	< 0.50	< 0.50	1.12	186.48
Brackish water (21 PSU)							
Oxyhalide anions							
Bromate	µg/L	1.34	1.84	33.57	1.51	45.92	48.15
Chlorate	mg/L	0.17	< 0.17	< 0.17	< 0.17	< 0.17	< 0.17
Perchlorate	µg/L	0.40	1.51	1.33	< 1.34	< 1.34	1.52
Trihalomethanes							
Dibromochloromethane	µg/L	1.65	3.42	7.97	2.75	7.24	6.68
Dichlorobromomethane	µg/L	1.24	4.95	14.14	3.40	4.32	4.55
Bromoform	µg/L	1.75	2.49	14.80	3.25	123.42	114.06
Chloroform	µg/L	1.34	7.64	39.91	4.92	6.25	6.50
Haloacetic acids							
Monochloroacetic acid	µg/L	0.10	< 0.10	< 0.10	< 0.10	< 0.10	< 0.10
Dichloroacetic acid	µg/L	0.06	0.35	< 0.06	< 0.06	< 0.06	< 0.06
Trichloroacetic acid	µg/L	0.07	0.19	< 0.07	0.18	< 0.07	< 0.07
Monobromoacetic acid	µg/L	0.09	< 0.09	0.22	< 0.09	< 0.09	< 0.09
Dibromoacetic acid	µg/L	0.06	< 0.06	1.46	< 0.06	10.70	9.87
Tribromoacetic acid	µg/L	0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05
Bromochloroacetic acid	µg/L	0.06	0.25	< 0.06	< 0.06	0.83	0.78
Dibromochloroacetic acid	µg/L	0.10	< 0.10	7.52	< 0.10	< 0.10	< 0.10
Dichlorobromoacetic acid	µg/L	0.06	< 0.06	< 0.06	< 0.06	< 0.06	< 0.06
Haloacetonitriles							
Chloropicrin	µg/L	0.02	0.94	1.27	1.34	1.12	0.99
Monobromoacetonitrile	µg/L	0.03	< 0.03	0.13	< 0.03	0.31	< 0.03
Dibromoacetonitrile	µg/L	0.02	< 0.02	4.49	< 0.02	< 0.02	< 0.02
Other halogenated chemicals							
2,4,6-Tribromophenol	mg/L	0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
1,2,3-Trichloropropane	µg/L	1.32	< 1.32	< 1.32	< 1.32	< 1.32	< 1.32
Thiosulfate	mg/L	0.50	< 0.50	< 0.50	< 0.50	1.54	246.82

^a MDL = Method Detection Limit

^b Treated water is divided into two types, before and after neutralization (discharge treated water)

3.4 Data on the efficacy of organism elimination from natural seawater (G8)

3.4.1 Preparation for the test

3.4.1.1 Cleaning tanks and pipes

The water tanks for the test were cleaned by fresh water to remove dirt and residues left over in the tanks. A few hours before each test took place, water from freshwater tanks was pumped into each ballast water tank in order to remove any leftovers from polluted water.

3.4.1.2 Test water

Test water was prepared in a 10 m³ tank using high salinity sea water at the Bay of Gamcheon, or brackish water which was made by adding tap water to seawater at the Bay of Gamcheon depending on the required salinity (> 32 PSU or 3-32 PSU, respectively, with a minimum difference of 10 PSU). Tap water was aerated for a few hours to remove chlorine which may be remaining. The 10 m³ of test water was used for both testing and control.

The combination of indigenous organisms and cultured surrogate species (> 50 µm: *Artemia salina*, 10-50 µm: *Tetraselmis* spp.) was added to fulfil the biological water quality criteria. One or more cultured species were used at the time, depending on the abundance of harvested indigenous organisms and culture conditions. Also, soluble glucose, soluble starch and silica sand were added to adjust the initial concentrations of dissolved organic carbon (DOC), particulate organic carbon (POC) and total suspended solids (TSS) to meet chemical water quality criteria.

3.4.2 Test methods

All nets for the concentration of organisms in the test site were strictly separated into three sets (each set uses 2 types of net; 7 µm mesh and 45 µm mesh in diagonal dimension) to avoid cross-contamination. All tests and analyses were performed in accordance with the Guidelines (G8) by internationally accredited laboratories (ISO/IEC 17025). Table 3.6 shows the analytical methods.

Table 3.6: Test methods

Items		Methods
Test water		
Temperature & salinity		APHA 2550 & APHA 2520
pH		APHA 4500-H+ B
Turbidity		APHA 2130B
Dissolved oxygen		APHA 4500-O G
POC & DOC		JGOFS (UNESCO, 1994)
TSS (Total Suspended Solids)		APHA 2540 D
Efficacy test		
Viable organisms	≥ 50 µm	ASTM E1440 (2004), ASTM E729 (2007)
	≥ 10-50 µm	Pouneval (1997), Susana & Carmen (2002)
Heterotrophic bacteria		JGOFS (UNESCO, 1994)
<i>Escherichia coli</i>		Gangar & Curiale (1999), 3M™ Petrifilm™ Plate manual
Intestinal Enterococci		APHA 9230C
Toxicogenic <i>Vibrio cholerae</i> (O1, O139)		APHA 9260H

Test water quality of each test is summarized in Table 3.7.

Table 3.7: A brief summary of water qualities of the test waters for lab scale test

	Temp. (°C)	Salinity (PSU)	DOC (mg/L)	POC (mg/L)	TSS (mg/L)	pH	D.O (mg/L)	Turbidity (NTU)
Test-1 (Seawater)	22.3	34.4	2.0	1.7	17.2	8.1	7.2	2.1
Test-2 (Brackish water)	23.8	21.5	5.4	6.0	52.4	8.0	7.5	12.5

3.4.3 Test results

All efficacy test results of the discharged treated water satisfy the standard described in regulation D-2 of the Convention and the results of the control water satisfied the water quality criteria of Guidelines (G8) (Table 3.8 and 3.9).

Table 3.8: Concentrations of viable organisms and heterotrophic bacteria in test water

Number of trial and date	Viable organisms		Heterotrophic bacteria (inds./mL)
	≥50 μm (inds./m ³)	≥10-50 μm (inds./mL)	
Seawater (>32 PSU)			
13 Jun. 2012	144,156	2,573	1.0E+06
Brackish water (3-32 PSU)			
04 Jul. 2012	126.833	1,981	1.0E+06

Table 3.9: Concentrations of viable organisms at control and treated water after 5 days

Number of trial and date	Viable organism				Bacteria (CFU/100 mL)*		
	≥50 µm (inds./m ³)		≥10-50 µm(inds./mL)				
	Control water	Treated water	Control water	Treated water	<i>Escherichia coli</i>	Toxicogenic <i>Vibrio cholerae</i> (O1, O139)	Intestinal Enterococci
Seawater (>32 PSU)							
18 Jun. 2012	11,558	8	109	ND	6	ND	ND
Brackish water (3-32 PSU)							
09 Jul. 2012	72,429	ND	137	ND	58	ND	ND

* Discharged treated water
ND = not detected.

3.5 Data on effects on aquatic plants, invertebrates and fish, and other biota, including sensitive and representative organisms ((G9): 4.2.1.1)

3.5.1 Acute aquatic toxicity

A search for ecotoxicity data was conducted to find existing aquatic ecotoxicity data for all of the substances associated with the Blue Zone™ BWMS. The data summarized in tables 3.10, 3.11 and 3.12 present the acute and chronic ecotoxicity data that was identified. However, a complete base-set for fish, crustaceans, and algae was not located for all substances and in some

cases the data did not meet the validity criteria. The data of ecotoxicity from literature has been provided as supporting information and is discussed in relation to the Predicted No Effect Concentration (PNEC) derivation in section 6.3.3.

Table 3.10 shows the acute ecotoxicity of the ozone used as an Active Substance for this system for the treatment of ballast water. Table 3.11 also shows the acute ecotoxicity of the Relevant Chemicals.

Table 3.10: Acute aquatic ecotoxicity of Active Substance from literature

	Species	Toxicity endpoint (duration)	Conc. (mg/L)	Reference
Ozone (Freshwater)				
F	<i>Catostomus commersoni</i>	LC ₅₀ (1.33 h)	1.43	US EPA ECOTOX
F	<i>Ictalurus punctatus</i>	LC ₅₀ (4d)	0.03	US EPA ECOTOX
F	<i>Lepomis macrochirus</i>	LC ₅₀ (1d)	0.06	US EPA ECOTOX
F	<i>Morone saxatilis</i>	LC ₅₀ (1.25d)	0.06	US EPA ECOTOX
F	<i>Oncorhynchus mykiss</i>	LC ₅₀ (4d)	0.0093	US EPA ECOTOX
Ozone (Seawater)				
F	<i>Morone americana</i>	LC ₅₀ (4d)	0.2	US EPA ECOTOX
F	<i>Morone saxatilis</i>	LC ₅₀ (4d)	0.08	US EPA ECOTOX

* F = fish, I = invertebrate, C = crustaceans, A = algae

Table 3.11: Acute aquatic ecotoxicity of Relevant Chemicals from literature

	Species	Toxicity endpoint (duration)	Conc. (mg/L)	Reference
Chloroform				
F	<i>Lepomis macrochirus</i>	LC ₅₀ (96h)	14	US EPA ECOTOX
F	<i>Cyprinus carpio</i>	EC ₅₀ (72-120h)	97	Mattice <i>et al.</i> (1981)
C	<i>Artemia salina</i>	LC ₅₀ (24h)	30	US EPA ECOTOX
A	<i>Scenedesmus subspicatus</i>	EC (48h)	950	Kuhn and Pattard (1990)
Bromoform				
F	<i>Cyprinodon variegates</i>	LC ₅₀ (72h)	18	US EPA ECOTOX
F	<i>Cyprinus carpio</i>	EC ₅₀ (72-120h)	52.3	Mattice <i>et al.</i> (1981)
C	<i>Daphnia magna</i>	EC ₅₀ (48h)	46	US EPA ECOTOX
A	<i>Skeletonema costatum</i>	EC ₅₀ (96h)	12.3	US EPA ECOTOX (1978)
Dibromochloromethane				
F	<i>Cyprinus carpio</i>	EC ₅₀ (72-120h)	34	Mattice <i>et al.</i> (1981)
I	<i>Tetrahymena pyriformis</i>	EC ₅₀ (24h)	650	US EPA ECOTOX
Dichlorobromomethane				
F	<i>Oryzias latipes</i>	LC ₅₀ (96h)	72	Toussaint <i>et al.</i> (2001)
F	<i>Cyprinus carpio</i>	EC ₅₀ (72-120h)	67.4	Mattice <i>et al.</i> (1981)
I	<i>Tetrahymena pyriformis</i>	EC ₅₀ (24h)	240	US EPA ECOTOX
Dichloroacetic acid				
C	<i>Daphnia magna</i>	EC ₅₀ (24h)	106	US EPA ECOTOX
C	<i>Nitocra spinipes</i>	LC ₅₀ (96h)	23	US EPA ECOTOX
Trichloroacetic acid				

F	<i>Pimephales promelas</i>	LC ₅₀ (96h)	2000	US EPA ECOTOX
C	<i>Daphnia magna</i>	EC ₅₀ (48h)	2000	US EPA ECOTOX
Dibromoacetic acid				
F	<i>Pimephales promelas</i>	LC ₅₀ (96h)	69	US EPA ECOTOX
Monobromoacetic acid				
F	<i>Cyprinus carpio</i>	LC ₅₀ (5h)	222	US EPA ECOTOX
C	<i>Daphnia magna</i>	LC ₅₀ (24h)	34	US EPA ECOTOX
A	<i>Scenedesmus subspicatus</i>	LC ₅₀ (48h)	0.34	Kuhn and Pattard (1990)
Monochloroacetic acid				
F	<i>Cyprinus carpio</i>	LC ₅₀ (28h)	191	US EPA ECOTOX
C	<i>Daphnia magna</i>	EC ₅₀ (48h)	96	Kuhn and Pattard (1990)
A	<i>Scenedesmus subspicatus</i>	EC ₅₀ (48h)	0.028	Kuhn and Pattard (1990)
Bromate				
F	<i>Morone saxatilis</i>	LC ₅₀ (96h)	30.8	Richardson <i>et al.</i> (1981)
C	<i>Neomysis awatschensis</i>	LC ₅₀ (24h)	176	US EPA ECOTOX
A	<i>Glenodinium halli</i>	EC ₅₀	13.6	Hutchinson <i>et al.</i> (1997)
Dibromoacetone (Freshwater)				
F	<i>Pimephales promelas</i>	EC ₅₀ (96h)	0.55	US EPA ECOTOX
2,4,6-Tribromophenol				
F	<i>Oryzias latipes</i>	LC ₅₀ (96h)	1.5	OECD SIDS (2003)
C	<i>Daphnia magna</i>	LC ₅₀ (96h)	1.1	OECD SIDS (2003)
A	<i>Selenastrum capricornutum</i>	EC ₅₀ (24-72h)	1.6	OECD SIDS (2003)
Sodium thiosulfate				
C	<i>Daphnia magna</i>	LC ₅₀ (4.2d)	805	US EPA ECOTOX
F	<i>Gambusia affinis</i>	LC ₅₀ (96h)	24,000	US EPA ECOTOX

* F = fish, I = invertebrate, C = crustaceans, A = algae

3.5.2 Chronic aquatic toxicity

No data exists on the chronic ecotoxicity of ozone. Ozone has a half-life period of 5.8 seconds in seawater and is supposed to be depredated in 30 minutes in the same way in freshwater as well. Thus, it is assumed that Ozone has no chronic toxicity.

For Relevant Chemicals, chronic ecotoxicity data is shown in Table 3.12 below.

Table 3.12: Chronic aquatic ecotoxicity of Relevant Chemicals from literature

	Species	Toxicity endpoint (duration)	Conc. (mg/L)	Reference
Chloroform				
F	<i>Oryzias latipes</i>	EC ₅₀ (9m)	1.5	Toussaint <i>et al.</i> (2001)
C	<i>Daphnia magna</i>	EC ₅₀ (21d)	13	US EPA ECOTOX
A	<i>Skeletonema costatum</i>	NOEC	477	Cowgill <i>et al.</i> (1989)
Bromoform				
F	<i>Cyprinodon variegatus</i>	EC ₅₀ (28d)	8.5	US EPA ECOTOX
A	<i>Pseudokirchneriella subcapitata</i>	EC ₅₀ (96h)	38.6	US EPA ECOTOX

Dichloroacetic acid				
A	<i>Scenedesmus subspicatus</i>	EC ₅₀ (7d)	1485	US EPA ECOTOX
Trichloroacetic acid				
A	<i>Scenedesmus quadricauda</i>	EC ₅₀ (7d)	200	OECD SIDS (2000)
Monobromoacetic acid				
C	<i>Daphnia magna</i>	EC ₅₀ (21d)	3.2	US EPA ECOTOX
A	<i>Scenedesmus subspicatus</i>	EC ₅₀ (3d)	1.4	Kuhn and Pattard (1990)
Monochloroacetic acid				
C	<i>Daphnia magna</i>	EC ₅₀ (21d)	32	Kuhn and Pattard (1990)
A	<i>Scenedesmus subspicatus</i>	EC ₅₀ (7d)	0.13	US EPA ECOTOX
Bromate				
F	<i>Morone saxatilis</i>	NOEC (10d)	92.6	Richardson <i>et al.</i> (1981)
F	<i>Leiostomus xanthurus</i>	NOEC (10d)	278.6	Richardson <i>et al.</i> (1981)
A	<i>Thalassiosira pseudonana</i>	NOEC (7d)	16	US EPA ECOTOX
2,4,6-Tribromophenol				
F	<i>Pimephales promelas</i>	NOEC (8d)	4.5	US EPA ECOTOX
C	<i>Daphnia magna</i>	EC ₅₀ (21d)	0.10	OECD SIDS (2003)
A	<i>Selenastrum capricornutum</i>	EC ₅₀ (72h)	1.0	OECD SIDS (2003)
Sodium thiosulfate				
A	<i>Nitzschia closterium</i>	NOEC (2d)	720	US EPA ECOTOX

* F = fish, I = invertebrate, C = crustaceans, A = algae

3.5.3 Endocrine disruption

An endocrine disrupting compound (EDC) was defined by the U.S. Environmental Protection Agency (EPA) as "an exogenous agent that interferes with synthesis, secretion, transport, metabolism, binding action, or elimination of natural blood-borne hormones that are present in the body and are responsible for homeostasis, reproduction, and developmental process".

No instance has been reported on the endocrine disruptive properties for ozone (as a result of research in the ECOTOX database). Because of the dissolution speed, it is considered that there is no internal disturbance.

In a recent study conducted to investigate whether chlorinated by-products formed through waste water disinfection were estrogenic, no relationship was found between the formation of THMs and estrogenic activity (Schiliro, 2009).

In fact, chlorination of surface water and effluents was found to decrease estrogenic activity, which is thought to be due to the oxidation effects of chlorine (Lee, 2004). A thorough review of the literature found no indications that either of the Active Substances in both ozone and the TRO as Cl₂ (HOCl/HOBr), or the chemically more complex THMs/HAAAs were EDCs.

In case of 2,4,6-tribromophenol (TBP), at concentrations of 300 µM or higher this effect may suggest a link to endocrine disruption. Due to the low concentration of 2,4,6-TBP (maximum concentration of < 0.001 µg/L, below MDL) (Table 3.5) detected in treated ballast water, and the limited routes of exposure in environmental waters, no endocrine effects would be expected as a result of treated ballast water discharge.

3.5.4 Sediment toxicity

The sediment toxicity of a chemical is a function of the ability of the chemical to be adsorbed to sediment as well as its persistence and toxicity. The organic carbon partition coefficient (K_{oc}) is a measure of the tendency of an organic substance to be absorbed by soil or sediment.

Ozone as Active Substance is generally known as a gas phase to treat polluted sediment *in situ*, which is acting to break the toxic organic pollutant such as PCBs down into by-products that bacteria can access.

The Active Substance and Relevant Chemicals are all inorganic substances and therefore have a very low calculated K_{oc} as presented in Table 3.13 below. All chemicals including Relevant Chemicals might not have the potential to be absorbed to sediments to a significant extent based on their low K_{oc} (< 500 L/kg) except for 2,4,6-TBP. The low K_{oc} for most of the chemicals in Table 3.13 indicate that the chemicals would not readily partition to sediment and therefore be of concern to benthic organisms residing in the sediment. Therefore, no sediment toxicity impacts are anticipated as a result of the Blue Zone™ ballast water discharge.

The K_{oc} for 2,4,6-TBP (1,186 L/kg) indicates moderate partitioning into sediment. When 2,4,6-TBP is released to water, 93% is expected to stay in the water compartment and 7% is transported to the sediment compartment (OECD SIDS, 2003). 2,4,6-tribromophenol is reported to dehalogenate rapidly in anaerobic sediments, with a reported half-life of approximately 4 days (CICADS 66, 2005). This is much more rapid than the sediment persistence criteria of 180 days in marine sediment and 120 days in fresh water sediment. Considering the low concentration of 2,4,6-TBP (maximum concentration of < 0.04 µg/L, below MDL) in ballast water discharge, a moderate potential for sediment adsorption and the rapid sediment degradation.

Table 3.13: K_{oc} values for Active Substance (AS) and Relevant Chemicals

Classification	Chemical	K_{oc} (L/kg)	Reference
AS	Ozone	23.74	EPI Suite v4.10
Oxyhalide Anions	Bromate	31.8	EPI Suite v4.10
	Chlorate	35.04	EPI Suite v4.10
	Perchlorate	48.64	EPI Suite v4.10
THMs	Dibromochloromethane	84	HSDB/TOXNET (2011)
	Dichlorobromomethane	9	HSDB/TOXNET (2011)
	Bromoform	35	HSDB/TOXNET (2011)
	Chloroform	153-196	HSDB/TOXNET (2011)
HAAs	Monochloroacetic acid	31	HSDB/TOXNET (2011)
	Dichloroacetic acid	75	HSDB/TOXNET (2011)
	Trichloroacetic acid	130	HSDB/TOXNET (2011)
	Monobromoacetic acid	1.9	HSDB/TOXNET (2011)
	Dibromoacetic acid	1.5	HSDB/TOXNET (2011)
	Tribromoacetic acid	5.3	HSDB/TOXNET (2011)
	Bromochloroacetic acid	1.9	HSDB/TOXNET (2011)
	Dibromochloroacetic acid	3.23	EPI Suite v4.10
	Dichlorobromoacetic acid	2.74	EPI Suite v4.10
HANs	Chloropicrin	381.65	ACD/PhysChem Suite
	Monobromoacetonitrile	8.3	EPI Suite v4.10
	Dibromoacetonitrile	12.83	EPI Suite v4.10

Classification	Chemical	K_{oc} (L/kg)	Reference
Other halogenated Chemicals	2,4,6-Tribromophenol (TBP)	1186	OECD SIDS (2003)
	1,2,3-Trichloropropane	130.8	EPI Suite v4.10
	Sodium thiosulfate	2.21	EPI Suite v4.10

3.5.5 Food web/population effects

The BCF is the best measure of bioavailability, biomagnification and bioconcentration for the assessment in the food web. This ecotoxicological property characterizes the accumulation of pollutants through chemical partitioning from the aqueous phase into an organic phase, such as the gill of a fish. Generally, a high potential BCF is greater than 1000, a moderate potential BCF is less than a 1000 but greater than 250, and a low potential BCF is less than 250. Typical BCFs for organic chemicals in fish and most aquatic invertebrates are in the 500-1,000 L/kg range.

The BCFs for Active Substances and Relevant Chemicals are all well below 1000 L/kg as presented in Table 3.14 below, indicating that they are unlikely to bioconcentrate/bioaccumulate in aquatic organisms. Limited biomagnification should occur in the food web since the chemicals are not readily bioconcentrated or bioaccumulated.

Table 3.14: BCFs for Active Substance (AS) and Relevant Chemicals

Classification	Chemical	BCF (L/kg)	Reference
AS	Ozone	3.16	EPI Suite v4.10
Oxyhalide Anions	Bromate	3.16	EPI Suite v4.10
	Chlorate	3.16	EPI Suite v4.10
	Perchlorate	3.16	EPI Suite v4.10
THMs	Dibromochloromethane	9	HSDB/TOXNET (2011)
	Dichlorobromomethane	7	HSDB/TOXNET (2011)
	Bromoform	14	HSDB/TOXNET (2011)
	Chloroform	2.9-10.35	HSDB/TOXNET (2011)
HAAs	Monochloroacetic acid	3.1	HSDB/TOXNET (2011)
	Dichloroacetic acid	0.3	HSDB/TOXNET (2011)
	Trichloroacetic acid	0.1-1.7	HSDB/TOXNET (2011)
	Monobromoacetic acid	3.2	HSDB/TOXNET (2011)
	Dibromoacetic acid	0.17	HSDB/TOXNET (2011)
	Tribromoacetic acid	0.63	HSDB/TOXNET (2011)
	Bromochloroacetic acid	3.2	HSDB/TOXNET (2011)
	Dibromochloroacetic acid	3.16	EPI Suite v4.10
	Dichlorobromoacetic acid	3.16	EPI Suite v4.10
HANs	Chloropicrin	3.16	EPI Suite v4.10
	Monobromoacetonitrile	1.58	EPI Suite v4.10
	Dibromoacetonitrile	2.95	EPI Suite v4.10
Other Halogenated Chemicals	2,4,6-Tribromophenol (TBP)	83-513	HSDB/TOXNET (2009)
	1,2,3-Trichloropropane	11.77	EPI Suite v4.10
	Sodium thiosulfate	0.0048	EPI Suite v4.10

Food web or population effects can occur if substances have properties that tend to bioaccumulate and/or persist in the environment. Limited biomagnification and persistence in aquatic and mammalian food webs is anticipated from the Relevant Chemicals. This conclusion is based on the low K_{oc} of the Active Substances and Relevant Chemicals.

All of the K_{oc} are < 500 L/kg which indicate that the chemicals would not readily absorb to sediment and therefore be a concern to benthic populations and their food webs. Similarly, the BCFs also show that little bioconcentration/bioaccumulation will occur in aquatic organisms. Therefore, no food web and/or population effects can be expected as a result of these Relevant Chemicals in the Blue Zone™ ballast water discharge.

3.6 Data on mammalian toxicity ((G9): 4.2.1.2)

In the mammalian toxicity studies reviewed, the chemicals were tested for various exposure routes (oral, dermal, etc.) and/or chemical forms, which do not necessarily reflect the actual potential exposure routes or chemical forms, associated with the Blue Zone™ BWMS. In some cases, data could not be located in the available literature.

3.6.1 Acute toxicity

Ozone concentrations in excess of a few tenths of a ppm (1 ppm = 2 mgm³, 20 °C, 101.3 kPa) cause occasional discomfort to exposed individuals in the form of headache, coughing, dryness of throat and mucous membranes and irritation of the nose following exposures of short duration. The odour threshold is about 0.02 ppm, however, a de-sensibilization occurs over time. Exposure to higher concentrations can also produce delayed lung edema in addition to lassitude, frontal headache, sensation of substernal pressure, constriction or oppression, acid in mouth, and anorexia. More severe exposures have produced dyspnea, coughing, choking sensation, tachycardia, vertigo, lowering of blood pressure, severe cramping chest pain, and generalized body pain. It is estimated that 50 ppm for 30 min would be fatal.

The data located in a literature search for acute mammalian studies for Relevant Chemicals is presented below.

Table 3.15: Acute mammalian toxicity data

Substance	Exposure Route	Species	Value Range	Reference
Bromate	Oral LD ₅₀	Rats, mice and hamsters	280-495 mg/kg	IPCS (2000)
Chlorate	a. Oral LD ₅₀ b. Dermal LD ₅₀ c. Inhalation LC ₅₀	a. rat b. rabbit c. rats	a. 5,000 mg/kg b. 2,000 mg/kg c. 5.59 mg/L	HSDB (2012)
Perchlorate	Oral LD ₅₀	Rat	2,100 mg/kg	MSDS (2012)
Dibromochloromethane	a. Oral LD ₅₀ b. Oral LD ₅₀	a. Male/female rats b. Male/female mice	a. 1186/848 mg/kg b. 800/1200 mg/kg	IPCS (2000)
Dichlorobromomethane	Oral LD ₅₀	Male/female rats	430/510 mg/kg	ATSDR & US EPA (1989)
Bromoform	a. Oral LD ₅₀ b. Oral LD ₅₀	a. Male/female rats b. Male/female mice	a. 1388/1147 mg/kg b. 1400/1550 mg/kg	IPCS (2000)

Chloroform	a. Oral LD ₅₀ b. Oral LD ₅₀ c. Inhalation LC ₅₀ , 6 h exposure	a. Rat b. Mice c. Rats	a. 450-2000 mg/kg b. 36-1366 mg/kg c. 9.2 g/m ³	IPCS (2004)
Monochloroacetic acid	a. Oral LD ₅₀ b. Skin LD ₅₀ c. Oral LD ₅₀	a. Mouse b. Rabbit c. Mice, male rats, and male guinea pigs	a. 260 mg/kg b. 230 mg/kg c. 255, 76, and 80 mg/kg respectively	a, b. IPCS (2000) c. WHO (2004b)
Dichloroacetic acid	a. Oral LD ₅₀ b. Oral LD ₅₀	a. Rat b. Mouse	a. 4500 mg/kg b. 5500 mg/kg	IPCS (2000)
Trichloroacetic acid	a. Oral LD ₅₀ b. Oral LD ₅₀	a. Rat b. Mice c. Rats	a. 450-2000 mg/kg b. 36-1366 mg/kg c. 9.2 g/m ³	IPCS (2004)
Monobromoacetic acid	Oral LD ₅₀	Rat	177 mg/kg	ICPS (2000)
Dibromoacetic acid	Oral LD ₅₀	Rat	1737 mg/kg	WHO (2004a)
Tribromoacetic acid	N/A	N/A	N/A	-
Bromochloroacetic acid	2-Week Oral drinking water study	a. Rat b. Mice	a. NOEL = 140 mg/kg/day b. NOEL = 170 mg/kg/day	NTP (2009)
Dibromochloroacetic acid	N/A	N/A	N/A	-
Dichlorobromoacetic acid	N/A	N/A	N/A	-
Chloropicrin	a. Oral LD ₅₀ b. Inhalation LC ₅₀	a. Rat b. Fischer 344, male	a. 37.5 mg/kg b. 6.6 ppm/4hr	HSDB (2012)
Monobromoacetonitrile	N/A	N/A	N/A	-
Dibromoacetonitrile	Oral LD ₅₀	Mouse, male	245 mg/kg	HSDB (2012)
2,4,6-Tribromophenol (TBP)	a. Acute oral LD ₅₀ b. Inhalation LC ₅₀ c. Acute dermal LD ₅₀	a. Rat b. Rat c. Rabbit	a. >5000 mg/kg b. >50 mg/L/4hr c. >8000 mg/kg	CICADS 66 (2005)
1,2,3-Trichloropropane	Dermal LD ₅₀	Rabbit	2,500 mg/kg	HSDB (2012)
Sodium thiosulfate	Oral LD ₅₀	Rats	>5,000 mg/kg	MSDS (2012)

3.6.2 Effects on skin and eye

Ozone as Active Substance is a highly toxic, oxidizing gas and can irritate the respiratory system. Thus ozone can cause coughing, irritate your throat, eyes, or nose, and cause headaches. These symptoms can last for a few hours after ozone exposure and may even become painful. Contact with ozone may irritate the skin. Burns and frostbite can also occur. Exposed persons may sense eye irritation at or above 0.1 ppm ozone.

Most THMs including chloroform and bromoform could cause an irritation to skin, consequently, causing redness and pain at levels of 13-34 µg/L. The sensitization to THMs may cause damage to the nervous system, heart, liver and kidneys. In addition, THMs have a greater risk of sensitizing those with pre-existing skin/respiratory problems.

Most HAAs could cause skin burns, redness and blisters in some cases. Especially trichloroacetic acid (TCAA) has toxicity that may cause corrosion, irritation, and moderate burns. The sensitization to HAAs, such as monochloroacetic acid and monobromoacetic acid may cause potential damage on liver, kidneys and muscles after chronic exposure.

Table 3.16: Skin, eye and dermal effects data

Chemical	Species results			Reference /comment
Dichlorobromomethane	Skin	Human	May be harmful if absorbed through skin. Cause skin irritation	MSDS- Sigma Aldrich
	Eyes	Human	Cause serious eye irritation	MSDS- Sigma Aldrich
	Respiratory	Human	May be harmful if inhaled. Causes respiratory tract irritation	MSDS- Sigma Aldrich
	Ingestion	Human	Harmful if swallowed	MSDS- Sigma Aldrich
Dibromochloromethane	Skin	Human	Irritant for skin and mucous membranes	MSDS-Alfa Aesar
	Eyes	Human	Irritant effect	MSDS-Alfa Aesar
	Respiratory	Human	Irritation of the respiratory tract, pharynx, and larynx, as well as lacrimation	MSDS-Alfa Aesar
Bromoform	Skin	Human	Irritant, permeator	MSDS- ScienceLab
	Eyes	Human	Irritation of the eyes and nose	HSDB/TOXNET (2011)
	Respiratory	Human	Irritation of the respiratory tract, pharynx, and larynx, as well as lacrimation	HSDB/TOXNET (2011)
Monobromoacetic acid	Skin	Human	Causes severe burns.	HSDB/TOXNET (2011)
	Eyes	Human	Causes severe burns.	HSDB/TOXNET (2011)
	Respiratory	Human	Extremely destructive to the tissue of the mucous membranes and upper respiratory tract.	HSDB/TOXNET (2011)

Chemical	Species results			Reference /comment
Dichloroacetic acid	Skin	Human	Extremely hazardous in case of skin contact. (corrosive, irritant) Very hazardous in case of skin contact (permeator)	MSDS-ScienceLab
	Eyes	Human	Extremely hazardous in case of eye contact (irritant)	MSDS-ScienceLab
Trichloroacetic acid	Skin	Human	Very hazardous in case of skin contact (irritant). Hazardous in case of skin contact (corrosive). Slightly hazardous in case of skin contact (permeator).	MSDS-ScienceLab
	Eyes	Human	Hazardous in case of eye contact (corrosive).	MSDS-ScienceLab
Bromochloroacetic acid	Skin	Human	May be harmful if absorbed through skin. Causes skin burns.	HSDB/TOXNET (2011)
	Respiratory	Human	Inhalation may result in spasm, inflammation and edema of the larynx and bronchi, chemical pneumonitis, and pulmonary edema	HSDB/TOXNET (2011)
Dibromoacetic acid	Skin	Human	May be harmful if absorbed through skin. Causes skin burns.	MSDS-Sigma aldrich
	Eyes	Human	Causes eye burns.	MSDS-Sigma aldrich
	Respiratory	Human	May be harmful if inhaled. Material is extremely destructive to the tissue of the mucous membranes and upper respiratory tract.	MSDS-Sigma aldrich
	Ingestion	Human	Harmful if swallowed. Causes burns.	MSDS-Sigma aldrich
Dichlorobromoacetic acid	Skin/eyes/nose	Human	This material is extremely destructive to tissue of the mucous membranes and upper respiratory tract, eyes, and skin.	HSDB/TOXNET (2011)
	Respiratory	Human	Inhalation may result in spasm, inflammation and edema of the larynx and bronchi, chemical pneumonitis, and pulmonary edema.	HSDB/TOXNET (2011)
Dibromochloroacetic acid	Inhalation	Human	May be harmful if inhaled. Material is extremely destructive to the tissue of the mucous membranes and upper respiratory tract.	MSDS-Sigma aldrich
	Skin	Human	May be harmful if absorbed through skin. Causes skin burns.	MSDS-Sigma aldrich
	Eyes	Human	Causes eye burns.	MSDS-Sigma aldrich
	Ingestion	Human	May be harmful if swallowed. Causes burns.	MSDS-Sigma aldrich

Chemical	Species results			Reference /comment
Tribromoacetic acid	Inhalation	Human	May be harmful if inhaled. Material is extremely destructive to the tissue of the mucous membranes and upper respiratory tract.	MSDS-Sigma aldrich
	Skin	Human	May be harmful if absorbed through skin. Causes severe skin burns.	MSDS-Sigma aldrich
	Eyes	Human	Causes eye burns.	MSDS-Sigma aldrich
	Ingestion	Human	May be harmful if swallowed. Causes severe burns.	MSDS-Sigma aldrich
Dibromoacetone	Skin	Human	Cause skin irritation.	HSDB/TOXNET (2011)
	Eyes	Human	Causes eye irritation.	HSDB/TOXNET (2011)
Sodium thiosulfate	Skin	Human	Slightly hazardous in case of skin contact (irritant, permeator).	MSDS-ScienceLab
	Eyes	Human	Hazardous in case of eye contact (irritant)	MSDS-ScienceLab

3.6.3 Repeated-dose toxicity

From the literature, it was found that repeated exposure to ozone has been demonstrated to have an effect upon lung function in animals at levels of 1-2 mg/kg.

In the case of THMs, most repeated dose toxicities on rats were reported in a range of 25-75 mg/kg/day exposed from 13 weeks to 6 months. Most literature on HAAs showed similar results as the THMs.

3.6.4 Chronic toxicity

Chronic exposure symptoms are similar to acute exposures with pulmonary lung function decrements depending on concentrations and duration of exposure. Asthma, allergies, and other respiratory disorders have been observed. Breathing disorders, tumorigenic, direct and indirect genetic damage have been found in animal and/or human tissue studies.

The data located in a literature search for chronic mammalian studies (six months or longer) is presented in Table 3.17 below.

Table 3.17: Chronic mammalian toxicity data

Substance	Exposure Route	Species	Value Range	Reference
Bromate	Oral, drinking water, 100 weeks a. 0-400 mg/L b. 0-800 mg/L	a. Rats b. Mice	a. kidney effects, NOAEL 1.1 mg/kg/d b. no effects, NOAEL >60 mg/kg/d	US EPA (2001a)
Chlorate	N/A	N/A	N/A	-

Substance	Exposure Route	Species	Value Range	Reference
Perchlorate	Oral, 14 days, 0.007-0.5 mg/kg/day	human	NOEL 0.007 mg/kg/day, thyroid radioiodide effect	US EPA (2005)
Dibromochloromethane	Oral gavage, 2-years a. 0/40/80 mg/kg/d b. 0/50/100 mg/kg/d c. Oral, 13 weeks, 0-250 mg/kg/day	a. Rats b. Mice c. F344/N Rats	a., b. Kidney and liver effects noted at all doses c. NOEL 21.4 mg/kg/day, Hepatic lesions effect	a., b. IPCS (2000) c. US EPA (1991b)
Dichlorobromomethane	a. Gavage, 104 week study, doses 5 days/week b. Gavage, 104 week study, doses 5 days/week	a. Rats b. Mice	a. NOAEL 100 mg/kg/day b. LOAEL 25 mg/kg/day (renal cytomegaly)	a. ATSDR & US EPA (1989) b. US EPA (1991c)
Bromoform	a. Gavage, 2-year, doses up to 200 mg/kg/day, b. Oral, 13 week, 0-200 mg/kg	a. Mice and rats b. F344/N rats	a. LOAEL 100 mg/kg/d (liver effects) b. NOEL 25 mg/kg/day (converted to 17.9 mg/kg/day)	a. IPCS (2000) ATSDR (2005) b. USEPA IRIS (1999a)
Chloroform	a. Oral, gavage, 2-years b. Oral, 7.5 years, toothpaste	a. Mice and rats b. Dogs	a. liver effects noted, including tumors b. LOAEL, 15 mg/kg/day (6 days/week)	a. IPCS (2004) b. ASTDR (1997)
Monochloroacetic acid	Oral, drinking water, 104 weeks, 0-59.9 mg/kg/day	Rats	NOAEL 3.5 mg/kg/day, changes in body weight	EU (2005)
Dichloroacetic acid	a, b. Oral, drinking water, 2 years, doses up to 2 g/L c. Subchronic Oral, 90 day	a. Rats b. Mice c. Dog	a. Dose dependent increase in liver tumor incidence, LOAEL 40 mg/kg/d, NOAEL 4 mg/kg/d b. 80% increase in liver tumor incidence at 95 mg/kg/d, c. LOAEL 12.5 mg/kg/day	a, b. IPCS (2000) c. US EPA (2003)
Trichloroacetic acid	Oral, 2-year, doses up to 5g/L	a. Rats b. Mice	a. liver effects, NOAEL 32.5 mg/kg/d b. dose-dependent increase in liver tumors, NOAEL 40 mg/kg/d	IPCS (2000) Health Canada (2009)
Monobromoacetic acid	Oral, 14 days 0, 25 or 100 mg/kg/day	Rats	NOAEL: 25 mg/kg/day (for 14 days), 100 mg/kg (single dose)	HSDB (2012)

Substance	Exposure Route	Species	Value Range	Reference
Dibromoacetic acid	Oral, drinking water, 2 years, 0-1000mg/L	a. Rats b. Mice	a. LOAEL 2mg/kg/d (liver effects in males, kidney effects in females) b. liver tumors, male: LOAEL 4/mg/kg/d, female: LOAEL 35/NOAEL 4 mg/kg/d	NTP (2007)
Tribromoacetic acid	N/A	N/A	N/A	-
Bromochloroacetic acid	Oral, drinking water, 2 years, 0-1000 mg/L a. 0-50 mg/kg b. 0-90 mg/kg	a. Rats b. Mice	a. NOAEL 13 mg/kg/d (non-neoplastic lesions in the liver) b. LOAEL 15 mg/kg/d (non-neoplastic and neoplastic liver effects)	NTP (2009)
Dibromochloroacetic acid	N/A	N/A	N/A	-
Dichlorobromoacetic acid	N/A	N/A	N/A	-
Chloropicrin	Oral, 90 days, 0-32 mg/kg	Rats	NOAEL 8 mg/kg/day, pulmonary complications effect	OEHHA (2001)
Monobromoacetone	N/A	N/A	N/A	-
Dibromoacetone	Oral, drinking water, 90 days	F344 Rats	NOAEL 11.3 mg/kg/day, decreased body weight	WHO (2004c)
2,4,6-Tribromophenol	N/A	N/A	N/A	-
1,2,3-Trichloropropane	Oral, 15 months, 0-30 mg/kg/day	F344/N Rats	NOAEL 5.71 mg/kg/day, Increased absolute liver weight, BMDL ₁₀ 1.6 mg/kg/day	USEPA (2009)
Thiosulfate	N/A	N/A	N/A	-

3.6.5 Developmental and reproductive toxicity

Developmental/reproductive toxicity of the Active Substance from only experiments with mice and rats have been reported examining the reproductive and teratological effects of ozone. Perinatal exposure of mice to 0.2 ppm reduced infant survival and increased the incidence of unlimited incisor growth (Brinkman *et al.*, 1964). Midgestational exposure of rats to 1.49 ppm resulted in a higher embryo resorption (Kavlock *et al.*, 1979), while late gestational exposure to 1 ppm slowed neonatal growth rates and delayed early reflex development and the onset of grooming and rearing behaviour (Kavlock *et al.*, 1980). Comparative studies with other mammals have not been reported. The implications for human reproduction and development are difficult to judge at present.

The concentration of TRO as Cl₂ in this application is controlled at < 0.2 mg/L as MADC and the chlorine is removed by neutralization prior to the discharge of ballast water. The

operations are conducted in sealed reactor and tanks. Living animals and organisms unlikely stay in the ballast water environment. Thus, the developmental and reproductive toxicity can be negligible.

The data on Relevant Chemicals located in a literature search for developmental and reproductive toxicity is presented in Table 3.18 below.

Table 3.18: Developmental and reproductive toxicity data

Chemical	Toxicity data	
Dichloro bromomethane	Exposure Route	Oral, 10 day 50-200 mg/kg/day on days 6-15 of gestation
	Species	Rats
	Effect	Dose from 50 mg/kg/day show fetotoxic effects
	Reference/Comment	HSDB/TOXNET (2011)
Dibromo chloromethane	Exposure Route	Oral, 6-15 days, 0, 5, 100 or 200mg/kg
	Species	Sprague-Dawley rats
	Effect	Maternal weight gain was significantly decreased from control values at the highest dose level. There was no increase in the incidence of resorptions or change in litter size or fetal body weight or in the incidence of external, visceral or skeletal malformations.
	Reference/Comment	HSDB/TOXNET (2011)
Bromoform	Exposure Route	Oral, 5 times weekly for 13 weeks, 100 to 200 mg/kg
	Species	Mice and rats
	Effect	Tribromomethane administered orally to male and female mice at up to 200mg/kg day had no significant effect on reproduction and fertility of the dosed animals.
	Reference/Comment	HSDB/TOXNET (2011)
Monobromoacetic acid	Exposure Route	Oral, 6-15 days, 0, 25, 50 or 100 mg/kg/day
	Species	Pregnant Long Evans rats
	Effect	Maternal weight increase was reduced and one female died during treatment at the highest dose. Reproductive performance was comparable across groups. The mean percent of resorbed implants per litter was not different from the controls at any dose. Live fetuses were significantly smaller at 100 mg/kg/day. The mean frequency of soft tissue malformations was significantly increased at the high dose. The defects were principally cardiovascular and craniofacial. LOAEL: 100 mg/kg/day
	Reference/Comment	HSDB /TOXNET (2011)
Dichloroacetic acid	Exposure Route	Oral (1), (2) gestation days 6 to 15. (3) 14 days, (1) 0, 14, 140 or 400 mg/kg/day (first study) 0, 900, 1400, 1900 or 2400 mg/kg/day (second study) (2) from 1,900 to 3,500 mg/kg/day (3) 0, 18, 54, 160, 480 or 1,440 mg/kg/day
	Species	(1), (2) rats (3) rats (male)
	Effect	(1) First study: reduced maternal body weight gain (≥ 140 mg/kg/day). Increased dose-related liver weights of dams (at all dose levels). Decreased dose-related fetal growth and increased the total soft tissue malformations (≥ 140 mg/kg/day). Second study: occurred dose-related mortality in treated dams. Increased post-implantation losses and reduced the number of live fetuses per litter (≥ 900 mg/kg/day). (2) Reduced fetal body weight in the

		offspring of dams. Fetal cardiac malformations in the offspring of pregnant dams. (3) Decreased epididymis weights (≥ 480 mg/kg/day). Increased the percentage of abnormal cauda sperm and decreased the percentage of motile sperm (≥ 160 mg/kg/day). Increased spermatotoxicity (≥ 54 mg/kg/day). NOAEL: (1) 14 mg/kg/day(maternal and developmental) (3) 18 mg/kg/day
	Reference/Comment	HSDB/TOXNET (2011)
Trichloroacetic acid	Exposure Route	Oral, 6-15 days, 0, 330, 800, 1200 or 1,800 mg/kg/day
	Species	Pregnant rats
	Effect	There were no maternal deaths associated with trichloroacetic acid exposure, however, weight gain was reduced at the 800 mg/kg/day and higher doses. Maternal spleen and kidney weights increased in a dose related manner. The mean percent of resorbed implants per litter was 34%, 62%, and 90% at 800, 1,200, and 1,800 mg/kg, respectively. Live fetuses showed dose dependent reductions in weight and length. The mean frequency of soft tissue malformations (principally in the cardiovascular system) ranged from 9% at the low dose to 97% at the high dose. Skeletal malformations (mainly in the orbit) were found only at the 1,200 and 1,800 mg/kg doses.
	Reference/Comment	HSDB/TOXNET (2011)
Bromochloroacetic acid	Exposure Route	Oral, 96h (beginning from stage 8 (mid-blastula) to stage 46 (when primary <i>organogenesis</i> is complete).), 0, 8,000, 10,000, 12,000 or 14,000ppm
	Species	Frog embryo (<i>Xenopus</i>)
	Effect	29, 83 and 100% mortality at 10,000, 12,000 and 14,000 pm, respectively. Incidence of malformations among surviving embryos at 96 h for 10,000 and 12,000 ppm BCA were 8.4 and 68%
	Reference/Comment	HSDB/TOXNET (2011)
	Exposure Route	Oral, 14 days, 0, 72 or 216 ppm
	Species	Sprague-Dawley rats (male)
	Effect	Male Sprague-Dawley rats for 14 days decreased epididymal sperm counts, decreased the number of motile sperm, increased the number of epididymal sperm with misshapen heads or tail defects, increased the number of atypical residual bodies in seminiferous tubules and increased the number of Step 19 spermatids retained in stages X and XI of the spermatogenic cycle
	Reference/Comment	HSDB/TOXNET (2011)
Dibromoacetic acid	Exposure Route	Oral, 14 days, 0, 1, 5 or 50 mg/kg/day
	Species	Female Dutch-belted rabbits
	Effect	No profound changes in gonadotropin profiles were observed. Although chronic exposure to dibromoacetic acid did not appear to have an effect on late follicular development or ovulation, dibromoacetic acid did reduce the population of primordial follicles. The long-term health consequences of diminished primordial follicles are unknown, but it is very likely that reproductive senescence would occur earlier.

	Reference/Comment	HSDB/TOXNET (2011)
Dichloro bromoacetic acid	Exposure Route	Exposing neurulation, 26h, 50 to 2,500µM
	Species	CD-1 mouse embryo
	Effect	Benchmark concentrations for induction of neural tube dysmorphogenesis were 63,500 and 536 µM for bromodichloroacetic acid. LOAEL: 536 µM
	Reference/Comment	HSDB/TOXNET (2011)
Dibromo chloroacetic acid	Exposure Route	Oral, 2 weeks, 0, 30, 100, 300, 750, 1,000 and 1,500 ppm/day
	Species	Rats
	Effect	Dibromochloroacetic acid at doses at and above 1,000 ppm produced consistent decreases in food and water consumption in both sexes, but did not result in any female reproductive toxicity or any visceral malformation or variations in any pups. In the male reproductive data, a decrease of 11% in the male sperm velocity samples was observed in the 1,500 ppm male.
	Reference/Comment	HSDB/TOXNET (2011)
Tribromo acetic acid	Exposure Route	100 to 200 mg/kg
	Species	Rats
	Effect	Tribromoacetic acid at up to 400 ppm marginally reduced water consumption and did not affect reproductive function or produce general toxicity. From these data, TBA is not a reproductive toxicant in males or females at doses up to 400 ppm
	Reference/Comment	HSDB/TOXNET (2011)
Dibromoacetonitrile	Exposure Route	Oral, 42 days, 50 mg/kg/day
	Species	Rats (female)
	Effect	The litters were culled on postnatal day 6 (to six to eight pups) and again at weaning, when litters were reduced to four pups, which were retained until 41 or 42 days of age. Four of the 26 dams treated with dibromoacetonitrile died. There was a significant decrease in maternal weight gain during the period of treatment.
	Reference/Comment	IARC MONOGRAPHS VOL.52 (1991)
Sodium thiosulfate	Exposure Route	Oral, Gestation day 6 to 15, 0, 5.5, 25.5, 118 or 550 mg/kg/day
	Species	Mice
	Effect	No indication of any effect on maternal or fetal survival. No incidence of visceral or skeletal abnormalities. The male/female ratios at the lowest and highest dose level are lower than other ratios.
	Reference/Comment	PMEP: Pesticide Management Education Program

3.6.6 Carcinogenicity

There is limited evidence that ozone causes cancer in animals. It may cause cancer of the lungs. Ozone is justifiably suspected of having carcinogenic potential (group B).

The data on Relevant Chemicals located in a literature search for carcinogenicity and mutagenicity including reproductive data is presented in Table 3.19 below.

Table 3.19: Carcinogenicity, mutagenicity and reproductive mammalian toxicity data

Chemicals	Carcinogenicity	Mutagenic	Reproductive	Reference
Bromate	B2	Some studies show that bromate is weakly mutagenic	Potential reproductive	US EPA (2001a)
Dibromochloro methane	C	N/A	No adequate data	US EPA (1991b)
Dichlorobromo methane	B2	Weak mutagenic effects in <i>S. cerevisiae</i> strains D7 and XV185-14C following exposure to dichlorobromomethane in the absence of liver homogenate.	No adequate data	US EPA (1991c)
Bromoform	B2	N/A	Inadequate data	USEPA (1999a)
Monochloroacetic acid	B2	Indicate that the potential for DNA damage and mutagenicity is probably low.	N/A	EU (2005)
Dichloroacetic acid	B2	Weak mutagen, inducing mutations and chromosome damage in <i>in vitro</i> and <i>in vivo</i> assays predominantly at high concentrations	Dosed male Long-Evans rats by oral gavage with 0, 31.25, 62.5, or 125 mg/kg-day dichloroacetate for 10 weeks and evaluated the reproductive effects	USEPA (2003)
1,2,3-Trichloropropane	2A	To bacteria and to cultured mammalian cells and binds to DNA of animals treated <i>in vivo</i> .	Obviously treatment-related reproductive effects were not observed in any of the experimental groups in either generation	USEPA (2009)

3.6.7 Mutagenicity / Genotoxicity

The putative chromosomal and mutagenic effects of ozone are most controversial. In both cases, very little comparative data is available, and the concentrations of ozone used were generally outside of ranges considered relevant for other physiological or biochemical parameters.

Ozone reacts *in vitro* with both DNA and RNA (Shinriki *et al.*, 1981). Thymidine and guanine are the two bases most easily destroyed by ozone in DNA and RNA, respectively.

Usually, dichloroacetic acid, trichloroacetic acid, and dichlorobromoacetic acid were known not to be genotoxic. The trend for both cytotoxicity and genotoxicity is iodinated HAAs > brominated HAAs > chlorinated HAAs.

Mutagenicity and genotoxicity of some DBPs such as bromoform, chloroform and dichloroacetic acid, which are detected at relatively higher concentrations than other DBPs, are the most likely negative effects according to a large number of studies. In the case of chloroform, it is able to induce micronucleus formation or chromosomal aberrations when the compound was orally administered in rats and mice but not in hamsters. Most of the reviews on bromoform and chloroform concluded that they are not strong mutagens but a weak genotoxic effect was not excluded.

The data on Relevant Chemicals located in a literature search for mutagenicity data is presented in table 3.19 above.

3.6.8 Toxicokinetics

Because of its high reactivity and low solubility in water, exposure to ozone via liquid or solid media is negligible and ozone uptake is thus almost exclusively by inhalation.

In literature of the total respiratory tract uptake, approximately 50% of inhaled ozone is deposited in the respiratory tract of rats; about half of that (i.e. 25%) is removed by the supralaryngeal airways (Hatch *et al.*, 1989). In humans, the total respiratory tract uptake is 80-95%, the efficiency being inversely proportional to flow rates and directly proportional to tidal volume. Uptake is similar in the nasal and oral airways in humans, accounting for about 30-40% of the respiratory tract uptake. The respiratory responses of humans exposed to ozone while breathing orally or nasally are similar, and this is consistent with these uptake observations (US EPA, 1996). The recent observations of Gerrity *et al.* (1995) and Hu *et al.* (1992) indicate that ozone uptake in the larger airways is greater than previously thought, although this is difficult to estimate precisely, some 20% of ozone inspired at rest may be removed in the larger airways.

Bromate is rapidly absorbed from the gastrointestinal tract, partially converted to bromide in tissues and excreted rapidly. In the case of chloroform, it will be well absorbed, metabolized, and eliminated rapidly by mammals after oral, inhalation, or dermal exposure. After bromoform is administered to mice and rats, 3-6 % and 5-14 % of this chemical will remain in body tissues after 36 or 48 hrs, respectively.

3.7 Data on environmental fate and effect under aerobic and anaerobic conditions ((G9): 4.2.1.3)

3.7.1 Modes of degradation (Biotic and Abiotic)

Ozone as Active Substance decomposes spontaneously during water treatment by a complex mechanism that involves the generation of hydroxyl free radicals. The hydroxyl free radicals are among the most reactive oxidizing agents in water. This is after all their mechanism of action and how they produce an oxidizing environment. As a consequence of this oxidizing environment, along with the presence of organic matter, THMs and HAAs are also produced. Biotic degradation for all of these simple halogenated organic compounds is in the order of days to weeks. Abiotic degradation of these compounds is longer. On the other hand, the half-life of hydroxyl free radicals is in the order of microseconds.

Degradation of TRO has two major routes: (1) through a quick consumption or decomposition by the chlorine demand in the polluted water (organic and nitrogen compounds, ions of Fe, Ni, Co that decompose TRO); and (2) through a slow decay via photolytic or heat decomposition.

In case of disinfection by ozone, HOBr/OBr⁻ form the equilibrium in a quick reaction with ozone. HOBr/OBr⁻ is removed from seawater by several mechanisms. HOBr/OBr⁻ will react with natural organic matter to form tribromomethane by the haloform reaction. In fact, a number of disinfection byproducts and other halogen containing compounds are reported when bromide is present in natural waters. Therefore, organic matter in ballast water could lead to the disappearance of the TRO. Sunlight can reduce HOBr/OBr⁻ to Br⁻ through a complex series of photochemical reactions. In some cases, where high concentrations of Cl⁻ are present, it may be that sunlight-mediated photolysis of HOBr /OBr⁻ leads to the formation of bromate ion. Therefore, photolysis may also lead to the loss of TRO.

The decay of TRO strongly influences the biological efficacy of Active Substance ozone aimed to eliminate organisms present in ballast water. Seawater characteristics, including the organic content and ammonia, affect the amount of ozone required to achieve a desired TRO level and rate of TRO decay, and therefore need to be considered in determining ozone requirements for ballast water treatment.

The rate of TRO decay seems dependant on salinity. Another of the two obvious effects would arise from differences in the organic carbon and/or ammonium concentrations and these are not sufficiently dissimilar to account for the difference in decay rate. Seawater of different sources has different concentrations of chemical compounds that affect TRO decay rates.

3.7.2 Persistence and identification of the main metabolites in the relevant media (ballast water, marine and fresh waters)

Due to their rapid degradation, Active Substances are not considered to be persistent in ballast water, marine or fresh water. Furthermore, due to the BCF and K_{oc} values, Active Substances will not tend to be bioaccumulated in the aquatic life and metabolites.

3.7.3 Bioaccumulation, partition coefficient, octanol/water partition coefficient

The literature reported and/or estimated BCFs are shown for the Active Substances and Relevant Chemicals in Table 3.14. Both Active Substances and all Relevant Chemicals have very low BCFs, indicating that they are unlikely to bioaccumulate in aquatic organisms or present a significant food chain risk. The organic carbon adsorption coefficient (K_{oc}) presented in Table 3.13 is the chemical adsorption coefficient normalized to the organic carbon content of soil or sediment. This parameter describes the tendency of a substance to bind to organic matter in the soil or sediment. Based on these data, these additional substances associated with the Blue ZoneTM BWMS have a low likelihood of bioaccumulation and partitioning to aquatic sediments.

With the exception of the THMs, all of the Active Substances and Relevant Chemicals have very low log K_{ow} 's, which indicates the compounds are hydrophilic. The THMs, as would be expected, are moderately hydrophobic. The log K_{ow} and BCF are related to each other with the BCF being the more relevant parameter to determine the likelihood of impacts of a chemical to aquatic organisms.

3.7.4 Bioavailability/biomagnification/bioconcentration

The bioconcentration factor (BCF) is the concentration of a particular chemical in a tissue per concentration of chemical in water (reported as L/kg). This physical property characterizes the accumulation of pollutants through chemical partitioning from the aqueous phase into an organic phase, such as fish or other aquatic organism tissues. The BCF is the best measure of bioavailability, biomagnification, and bioconcentration. Typical BCFs for organic chemicals in

fish and most aquatic invertebrates are in the 500-1,000 range. The BCFs summarized in Table 3.14 above are all much lower indicating a low potential for significant bioconcentration/bioaccumulation in aquatic organisms. Limited biomagnification should occur in the food web since the chemicals are not readily bioconcentrated or bioaccumulated.

3.7.5 Reaction with organic matter

The formation of disinfection by-products (DBPs) when using ozone-based water disinfection methods is well known. DBP formation is a result of disinfectant reactions with natural organic matter, often measured as total organic carbon (TOC), which serves as the organic precursor (IPCS, 2000). Water quality (e.g., pH, temperature, hydroxyl free radicals, TOC) and treatment conditions (e.g., ozone dose, contact time, removal of organic matter prior to treatment) influences the formation of DBPs as a result of organic matter reactions. Further, the distribution of DBP species (up to four THM species, up to nine HAA species) is affected by the amounts of TOC, oxidation of bromide ion (IPCS, 2000). Analysis to quantify DBP concentrations in ballast water discharge was conducted during testing of the Blue ZoneTM BWMS.

3.7.6 Potential physical effects on wildlife and benthic habitats

No reports are found in the literature on the physical effects on wildlife and benthic habitats. However, based on the acute and chronic ecotoxicity related data previously discussed and the ecotoxicity study of our treated ballast water, the physical effects are not expected to occur because the treated water is neutralized (i.e. remove TRO) prior to discharge in the operation of the technology in this application.

3.7.7 Potential residues in seafood

Chemicals measured in treated ballast water discharge may pose a threat to seafood consumers only if they tend to bioaccumulate (within a trophic level, an increase in concentration of a substance in tissues due to uptake from food and sediments) or biomagnify (an increase in the concentration of a substance in the food web). The chemicals identified in this report all have Log K_{ow} less than 3 and BCF less than 2000, and are therefore not expected to persist in the food web.

3.7.8 Any known interactive effects

No other interactive effects are known from the literature.

3.8 Physical and chemical properties for the Active Substances, Relevant Chemicals and treated ballast water ((G9): 4.2.1.4)

3.8.1 Physical and chemical properties of the substances

Available chemical property data for these three additional substances is provided in Tables 3.20 and 3.21 below.

Table 3.20: Physical and chemical properties of Active Substance

Physical/Chemical Property	Abbreviation	Ozone
Melting point (°C)	MP	-193
Boiling point (°C)	BP	-112
Flammability (flash point for liquids; °C)	FL	Not applicable
Density (20°C; kg/m ³)	DS	Not applicable
Viscosity (20°C)	VS	Not applicable

Physical/Chemical Property	Abbreviation	Ozone
Vapor pressure / Vapor density (air = 1)	VP	> 1 atm
Water solubility (temp; effect of pH; mg/L) / Dissociation constant (pKa)	WS	570 mg/L at 20 °C
Henry's law constant	HL	2.431E-016 atm-m ³ /mole
Corrosivity to materials	CS	Corrosive
Oxidizing properties	OP	Strong oxidizing agent

Table 3.21: Physical and chemical properties of Relevant Chemicals

Chemicals	*MP	*BP	*FL	*DS	*VP	*WS	*HL	*CR	*OP
Bromate	206	517.3	Not found	Not found	5.53E-011 mmHg (25°C)	1000 g/L	1.135E-019 atm-m ³ /mole	Not found	Oxidizing agent
Chlorate	194.0	497.0	Not found	Not found	3.85E-012 (25°C)	1000 g/L	4.279E-019 atm-m ³ /mole	Not found	No data available
Perchlorate	193.6	492.0	Not found	Not found	5.55E-012 (25°C)	1e+003 g/L	7.336E-019 atm-m ³ /mole	Not found	No data available
Dibromochloromethane	-22	117.1	Non-flammable	2.504	21 mmHg (25°C)	2.7 g/L (20°C)	7.537E-003 atm-m ³ /mole	Not found	No data available
Dichlorobromomethane	-55	89.7	Non-flammable	1.98 at 25 °C	65.3 mmHg (25°C)	4.7 g/L (22°C)	9.614E-003 atm-m ³ /mole	Not found	No data available
Bromoform	9	142.9	Non-flammable	2.974	5 mmHg (20°C)/ 8.7	3.1 g/L (25°C)	54.2 Pa.m ³ /mol (25°C, estimated)	Corrosive	No data available
Chloroform	-63.5	61.3	Non-flammable	1.48	197 mmHg (25°C)	8.7 g/L (23°C)	367 Pa.m ³ /mol at 25°C	Corrosive	Strong oxidizing agent
Monochloroacetic acid	61-63	189	126°C (closed cup)	1.399	0.065 mmHg (25°C)/ 3.26	858 g/L (25°C)/ pKa=2.87	9.42E-009 atm-m ³ /mole	Not found	No data available
Dichloroacetic acid	9-11	194	113°C	1.575	0.179 mmHg (25°C)/ 4.45	Miscible with water/pKa=1.26	3.52E-007 atm-m ³ /mole	Corrosive	No data available
Trichloroacetic acid	52-58	196.5	198°C	1.808	0.06 mmHg (25°C)	54 g/L (25°C)/ pPa=0.51	1.35E-008 atm-m ³ /mole	Corrosive	No data available

Chemicals	*MP	*BP	*FL	*DS	*VP	*WS	*HL	*CR	*OP
Monobrom oacetic acid	47-49	207	113°C (closed cup)	2.003	0.119 mmHg (25°C)	1750 g/L (25°C)/ pKa=2.89	8.88E-008 atm-m ³ /mole	Corrosive	No data available
Dibromoa cetic acid	32-38	238.4	113°C (closed cup)	2.627	0.023 mmHg (25°C)	2100 g/L (25°C)/ pKa=1.48	7.27E-009 atm-m ³ /mole	Not found	No data available
Tribromoa cetic acid	131	245	Not found	3.099	0.009 mmHg (25°C)	1.1 g/L (25°C)	9.885E-008 atm-m ³ /mole	Corrosive	No data available
Bromochlo roacetic acid	35.69	244.6	110°C (closed cup)	2.138	0.14 mmHg (25°C)	250 g/L (25°C)/ pKa=1.4	2.22E-008 atm-m ³ /mole	Corrosive	No data available
Dibromoc hloroacetic acid	68.1	217.7	Not found	2.685	0.05 mmHg (25°C)	2.4 g/L (25°C)	7.322E-007 atm-m ³ /mole	Not found	No data available
Dichlorobr omoacetic acid	47.9	234.6	Not found	2.225	0.134 mmHg (25°C)	4.9 g/L (25°C)	2.022E-006 atm-m ³ /mole	Not found	No data available
Chloropicrin	-69.2	112.4	Not found	1.786	18 mmHg	1.058e+002 g/L (25°C)	1.382E-013 atm-m ³ /mole	Not found	Strong oxidizers
Dibromoa cetonitrile	6.98	203.6	Flammabl e	2.435	2.1 mmHg (25°C)	9.6 g/L (25°C)	8.203E-006 atm-m ³ /mole	Corrosive	No data available
Monobromo acetoneitrile	-31.56	150	Not found	1.761	3.18 mmHg (25°C)	107 g/L (25°C)	1.849E-005 atm-m ³ /mole	Corrosive	No data available
2,4,6-Tribromop henol	94	282-290	Not found	2.425	0.00146 mm Hg (25°C)	0.07 g/L (25°C)	1.445E-005 atm-m ³ /mole	Not found	No data available
1,2,3-Trichloropr opene	-46.9	162.2	Not found	Not found	3.69 mm Hg (25°C)	1.75 g/L (25°C)	6.251E-004 atm-m ³ /mole	Not found	strong caustics & oxidizers
Sodium thiosulfate	48.3	100	Non-flammable	1.667	negligible	210 g/L (20°C)	No data availabl e	Not found	No data available

* MP=Melting point (°C), BP=Boiling point (°C), FL=Flammability (flash point for liquids; °C), DS=Density (20°C; kg/m³), VP=Vapor pressure / Vapor density (air = 1), WS=Water solubility (temp; effect of pH; mg/L) / Dissociation constant (pKa), HL=Henry's law constant, CR=Corrosivity to materials, OP=Oxidizing properties

3.8.2 Corrosivity

A corrosivity test was not conducted with treated ballast water from the Blue Zone™ BWMS in this dossier for Basic Approval. The full corrosion testing will be carried out during 6 months in accordance with the recommendations provided in section 5.1 of the Report of the eighth meeting of the GESAMP-BWWG set out in document MEPC 59/2/16 in the application for Final Approval of the BWMS.

3.9 Analytical methods at environmentally relevant concentrations ((G9): 4.2.1.5)

All analyses were done according to standard methods such as aquatic ecotoxicity testing performed under supervision of KIOST. The chemical analysis laboratory, LabFrontier Co., Ltd is accredited by KOLAS for chemical analysis of environmental samples.

Treated ballast water samples were collected immediately after neutralization at discharge including water sample before neutralization. Samples for chemical analysis were stored in proper sample containers at 4°C and transported to the designated laboratory within 12 hours of collection. Analysis of the samples occurred within the time specified under standard laboratory procedures. Qualified and accredited laboratories were utilized for analysis of treated water samples. Acceptable field-testing analytical methods were also used where applicable (e.g., TRO as Cl₂). The methods used to determine DBP concentrations are listed in Table 3.22 below. Information regarding quality assurance from the analytical laboratories is included in appendix IV.

Table 3.22: List of analytical methods for TRO and Relevant Chemicals

Relevant Chemical	Unit	*MDL	Standard Protocol	Analytical Method
Total Residual Oxidant	mg/L	0.02	EPA 330.3; 1978	Total Residual (Titrimetric, Iodometric)
Bromate	µg/L	1.34	ISO 15061; 2001	By Ion Chromatography Inductively Coupled Plasma- Mass Spectrometry
Chlorate	mg/L	0.17	EPA 300.1; 1997	By Ion Chromatography
Perchlorate	µg/L	0.40	EPA 314; 1999	BY Liquid Chromatography ESI Mass Spectrometry
Dibromochloromethane	µg/L	1.65	EPA 524.2; 1995	By Capillary Column Gas Chromatography/Mass Spectrometry
Dichlorobromomethane	µg/L	1.24		
Bromoform	µg/L	1.75		
Chloroform	µg/L	1.34		
Monochloroacetic acid	µg/L	0.10	EPA 552.2; 1995	By Liquid-liquid Extraction Derivatization and Gas Chromatography with Electron Capture Detection
Dichloroacetic acid	µg/L	0.06		
Trichloroacetic acid	µg/L	0.07		
Monobromoacetic acid	µg/L	0.09		
Dibromoacetic acid	µg/L	0.06		
Tribromoacetic acid	µg/L	0.05		
Bromochloroacetic acid	µg/L	0.06		
Dibromochloroacetic acid	µg/L	0.10		
Dichlorobromoacetic acid	µg/L	0.06		
Chloropicrin	µg/L	0.02	EPA 551.1;	By Liquid-liquid Extraction and Gas

Relevant Chemical	Unit	*MDL	Standard Protocol	Analytical Method
Dibromoacetonitrile	µg/L	0.03	1995	Chromatography with Electron Capture Detection
Monobromoacetonitrile	µg/L	0.02		
2,4,6-Tribromophenol	mg/L	0.001	EPA 528; 2000	By Solid Phase Extraction and Capillary Column Gas Chromatography/Mass spectrometry
1,2,3-Trichloropropane	µg/L	1.32	EPA 524.2; 1995	By Capillary Column Gas Chromatography/Mass Spectrometry
Thiosulfate	mg/L	0.50	ISO 10636; 1994	Photography-Processing Chemicals

* MDL=Method Detection Limit

4 THE USE OF ACTIVE SUBSTANCE ((G9): 4.2.6)

4.1 The manner of application

In the Blue Zone™ BWMS, the TRO is automatically controlled by HMI and PLC. To control the TRO automatically, parameters should be input to the PLC by the operator.

During the ballasting process, the micro-sized ozone bubbles make the contact surface between the seawater and ozone gas larger.

The neutralization module of the Blue Zone™ BWMS is designed for ballast water to be discharged once the TRO value is less than MADC. Thiosulfate used as neutralizer is injected into the de-ballasting pipe to neutralize the remaining TRO. The injection rate of thiosulfate is controlled to maintain below the MADC of 0.2 mg/L TRO as Cl₂.

The micro bubble generation device of the Blue Zone™ BWMS is directly installed into the ballast water pipe. In this system, ballast water flows into the micro bubble generation device through a pipe and is stored in the ballast water tank. Also, as a neutralizing agent is supplied by being directly connected to the pipe, it does not have any harmful effect on ships' crew. Therefore, ships' crew cannot be exposed to AS and RC contained in treated water. Even during the voyage, since treated water is stored in the ballast water tank, ships' crew have no chance to be exposed to AS and RC contained in treated water.

The Blue Zone™ BWMS is designed to operate with minimal input parameters for the operator or ship's crew.

Please refer to section 3.1, Description of the Blue Zone™ BWMS, section 3.3, Identification of Active Substances or Preparation, and section 3.4, Results of biological efficacy testing. Details of operation and safety for Blue Zone™ BWMS are contained in appendix XII.

For the safe operation of the Blue Zone™ BWMS, instructions are provided. Also, a TRO sensor, ozone destructor and ozone analyser are installed in ships for safety.

Operators, including ships' crew, who sample ballast water or clean ballast tanks, are easily exposed to AS or RC. Therefore, as recommended in MSDS, operators must wear Personal Protective Equipment such as safety gloves, clothing and goggles. If the skin and eyes of the operator are exposed to AS or RC, they have to rinse them with freshwater immediately.

These procedures shall be included in the operation manual for the land-based test.

Also, the Ship Safety Manual of the Blue Zone™ BWMS for operation will be provided based on the appendix XII.. In connection with the risk assessment, the manual is considered to avoid uncontrolled or emergency situations in a safe manner.

5 RISK CHARACTERIZATION – HUMAN HEALTH

5.1 Hazard identification

Human Exposure Scenario

The possible receptors here can be (1) occupational, the ship crew and/or port State inspectors for the operation and maintenance of the BWMS (the workers), and (2) general public, general human populations which can be exposed to the chemicals of concern (COCs) via the environment where treated ballast water is discharged, by consumption of seafood and swimming in the surrounding area.

Different exposure scenarios should be developed for each receptor group. All human receptors can be exposed to the COCs via ingestion or dermal as well as the inhalation route. Depending on the scenario developed, the importance of each exposure route can be varied.

The operation and maintenance may include the usual operation of the system during ballasting and de-ballasting, cleaning work, repairing work and all other maintenance process. Since the worker should wear suitable protective clothing, gloves and shoes, the possibility for the exposure of COCs in the water treated by the BWMS to workers will be very low. To assess the potential risk under a worst-case situation, it is assumed that the workers do not wear protective clothing and gloves.

The Blue Zone™ BWMS is a closed system, so it is very unlikely that the worker/operator is exposed to the COCs vaporized from the pipeline or ballast tank. However, the maximum level of COCs was estimated and used for the risk assessment of both occupational and public exposure.

For the concerns of the workers or ship crews who have the greatest potential for exposure to COCs, they can be exposed when an accidental event (spillage, leakage, etc.) occurs. The most important exposure scenarios are listed below:

- .1 Ballast water sampling;
- .2 Periodic ballast tank cleaning;
- .3 Ballast tank inspection; and
- .4 Normal working on the deck (not related to BWMS work).

The possible exposure scenario for the public is the consumption of seafood and swimming in the surrounding area where the ballast water is discharged.

For the concerns of the general public population:

- .1 Swimming in the sea where ballast water is discharging; and
- .2 Eating seafood exposed to the discharged ballast water.

The representative uptake routes of chemicals including ingestion, dermal absorption and inhalation should be considered for each exposure scenario. Then all the feasible uptake route(s) were selected to calculate exposure amount for each scenario.

Chemicals of concern

The chemicals of concern (COCs) in water samples treated by Blue Zone™ BWMS were analyzed at day 0 and day 5 in both seawater and brackish water (presented in Table 1.1 of appendix VII). Among RCs, concentrations of 15 chemicals were higher in the treated water than untreated water either in brackish water or seawater. Those chemicals were assessed for human health risk related to the maintenance and discharging of ballast water treated by Blue Zone™ BWMS (Table 5.1).

In this human health risk assessment, different chemical data were used for occupational and general public population, considering the different exposure conditions. For occupational exposure, maximum concentration among all treated water samples regardless of sampling time (D0 or D5) was used and maximum PEC estimated by MAMPEC (ver. 3.0) model was used for public exposure to assess risks under worst-case conditions.

5.2 Exposure assessment

The process of exposure assessment includes the development of human exposure algorithms for all possible receptor groups. Under each exposure scenario, the most reliable information for each exposure factor was referred from literature and used to quantify the exposure of COCs.

Occupational and general public exposures to each COC were estimated under various scenarios. The exposure amount of ship crews is shown in Table 5.1 and those of public population in Table 5.2.

Table 5.1 Exposure amount of ship crews

Substance	Sampling		Cleaning tank		Tank inspection	Normal work	Worker total ADD
	Inhalation	Dermal	Inhalation	Dermal	Inhalation	Inhalation	
Bromate	5.8.E-19	7.4.E-06	5.2.E-20	7.4.E-06	4.7.E-23	2.3.E-22	1.5.E-05
Dibromochloromethane	7.6.E-04	1.1.E-06	6.8.E-05	1.1.E-06	6.1.E-08	3.1.E-07	8.3.E-04
Dichlorobromomethane	1.0.E-08	7.1.E-07	9.2.E-10	7.1.E-07	8.3.E-13	4.1.E-12	1.4.E-06
Bromoform	7.0.E-03	1.9.E-05	6.3.E-04	1.9.E-05	5.6.E-07	2.8.E-06	7.7.E-03
Chloroform	2.5.E-03	1.0.E-06	2.2.E-04	1.0.E-06	2.0.E-07	1.0.E-06	2.7.E-03
Dichloroacetic acid	1.1.E-14	1.8.E-07	9.3.E-16	1.8.E-07	8.4.E-19	4.2.E-18	3.7.E-07
Monobromoacetic acid	5.7.E-10	1.3.E-07	5.1.E-11	1.3.E-07	4.6.E-14	2.3.E-13	2.5.E-07
Dibromoacetic acid	5.1.E-09	1.6.E-06	4.5.E-10	1.6.E-06	4.0.E-13	2.0.E-12	3.3.E-06
Tribromoacetic acid	1.2.E-09	5.0.E-07	1.0.E-10	5.0.E-07	9.2.E-14	4.6.E-13	1.0.E-06
Bromochloroacetic acid	2.0.E-09	1.8.E-07	1.8.E-10	1.8.E-07	1.6.E-13	8.2.E-13	3.6.E-07
Dibromochloroacetic acid	3.7.E-14	2.1.E-06	3.3.E-15	2.1.E-06	2.9.E-18	1.5.E-17	4.1.E-06

Substance	Sampling		Cleaning tank		Tank inspection	Normal work	Worker total ADD
	Inhalation	Dermal	Inhalation	Dermal	Inhalation	Inhalation	
Dichlorobromoacetic acid	3.7.E-15	6.8.E-08	3.3.E-16	6.8.E-08	2.9.E-19	1.5.E-18	1.4.E-07
Chloropicrin	3.1.E-09	2.2.E-07	2.7.E-10	2.2.E-07	2.5.E-13	1.2.E-12	4.4.E-07
Monobromoacetonitrile	6.8.E-13	2.5.E-07	6.1.E-14	2.5.E-07	5.5.E-17	2.7.E-16	4.9.E-07
Dibromoacetonitrile	3.8.E-07	1.3.E-06	3.4.E-08	1.3.E-06	3.0.E-11	1.5.E-10	3.1.E-06

Table 5.2: Exposure amount of public population

Substances	Swimming RCR			Eating seafood	Public total ADD
	Inhalation	Dermal	Chemical swallowed	Eating fish	
Bromate	1.2.E-23	7.8.E-07	1.0.E-07	N.C.	8.8.E-07
Dibromochloromethane	5.2.E-09	4.0.E-08	5.1.E-09	2.5.E-07	3.0.E-07
Dichlorobromomethane	1.9.E-13	6.8.E-08	8.8.E-09	3.3.E-07	4.1.E-07
Bromoform	5.9.E-08	8.3.E-07	1.1.E-07	2.2.E-06	3.2.E-06
Chloroform	8.1.E-08	1.7.E-07	2.1.E-08	3.3.E-07	6.0.E-07
Dichloroacetic acid	7.9.E-20	7.1.E-09	9.2.E-10	1.5.E-09	9.5.E-09
Monobromoacetic acid	7.0.E-15	8.0.E-09	1.0.E-09	1.8.E-08	2.7.E-08
Dibromoacetic acid	1.1.E-13	1.8.E-07	2.3.E-08	2.1.E-08	2.2.E-07
Tribromoacetic acid	2.2.E-14	4.9.E-08	6.4.E-09	2.2.E-08	7.7.E-08
Bromochloroacetic acid	3.7.E-14	1.7.E-08	2.2.E-09	3.7.E-08	5.6.E-08
Dibromochloroacetic acid	4.3.E-19	1.3.E-07	1.6.E-08	2.8.E-07	4.2.E-07
Dichlorobromoacetic acid	4.5.E-20	4.3.E-09	5.6.E-10	N.C.	4.9.E-09
Chloropicrin	6.4.E-14	2.4.E-08	3.1.E-09	1.3.E-07	1.6.E-07
Monobromoacetonitrile	1.4.E-17	2.7.E-08	3.4.E-09	2.9.E-08	5.9.E-08
Dibromoacetonitrile	4.1.E-12	7.5.E-08	9.7.E-09	1.5.E-07	2.4.E-07

5.3 Effect assessment

Effect assessment estimated potential risks to receptors at exposure levels of interest. During the effect assessment process, the toxicity data for COCs are compiled by reviewing a variety of toxicological data from reliable literature and databases. Detailed toxicity information is presented in Table 5.3.

Table 5.3: Results of the effect assessment of COCs

Substances	^a NOAEL (mg/kg/d)	DNEL _{inh-8h-la} (mg/m ³)	DNEL _{inh-24h-ba} (mg/m ³)	DNEL _{inh-2.5h-la} (mg/m ³)	DNEL _{oral} (mg/kg/d)
Bromate	1.1	3.83.E-02	1.91.E-02	1.22.E-01	5.50.E-03
Dibromochloromethane	21.4	7.44.E-01	3.72.E-01	2.38.E+00	1.07.E-01
Dichlorobromomethane	17.9	6.23.E-01	3.11.E-01	1.99.E+00	8.95.E-02
Bromoform	17.9	6.23.E-01	3.11.E-01	1.99.E+00	8.95.E-02
Chloroform	15	5.22.E-01	2.61.E-01	1.67.E+00	2.14.E-01
Monochloroacetic acid	12.5	4.35.E-01	2.17.E-01	1.39.E+00	1.79.E-01
Dichloroacetic acid	2	6.96.E-02	3.48.E-02	2.23.E-01	1.00.E-02
Trichloroacetic acid	2	6.96.E-02	3.48.E-02	2.23.E-01	1.00.E-02

Substances	^a NOAEL (mg/kg/d)	DNEL _{inh-8h-la} (mg/m ³)	DNEL _{inh-24h-ba} (mg/m ³)	DNEL _{inh-2.5h-la} (mg/m ³)	DNEL _{oral} (mg/kg/d)
Dibromoacetic acid	2	6.96.E-02	3.48.E-02	2.23.E-01	1.00.E-02
Bromochloroacetic acid	13	4.52.E-01	2.26.E-01	1.45.E+00	6.50.E-02
Dibromochloroacetic acid	2	6.96.E-02	3.48.E-02	2.23.E-01	1.00.E-02
Dichlorobromoacetic acid	2	6.96.E-02	3.48.E-02	2.23.E-01	1.00.E-02
Chloropicrin	8	2.78.E-01	1.39.E-01	8.90.E-01	4.00.E-02
Monobromoacetonitrile	11.3	3.93.E-01	1.97.E-01	1.26.E+00	5.65.E-02
Dibromoacetonitrile	11.3	3.93.E-01	1.97.E-01	1.26.E+00	5.65.E-02

^a Toxicity (NOAEL) data for these 6 chemicals was not available, therefore the AFs for similar compounds were used instead.

5.4 Risk Characterization

Finally, the risk characterization process is a comparison of the exposure level to various Derived No Effect Levels (DNELs). The RCR is calculated according to the following formula:

$$RCR = Exposure / DNEL$$

If the $RCR < 1$, the exposure is deemed to be safe. However, risk are regarded to be controlled when the estimated exposure levels do not exceed the predicted no effect levels (DNEL), that is if the $RCR \geq 1$.

The risk characterization ratios for human receptors including occupational such as operator, ship crew and general public, were all below the acceptable risk level (Tables 7.1 and 7.2), which means the potential risk of COCs related to the Blue Zone™ BWMS will be low enough even under conservative assumptions for the exposure conditions. The detail for the procedure of risk characterization estimation of COCs is shown in appendix VII.

No occupational or public exposure (average daily dose, ADD) to COC exceeded DNEL in this assessment (Table 5.3). RCRs of the aggregated exposure of all scenarios were also less than 1, indicating that the Blue Zone™ BWMS may pose negligible risk to both workers and the general public.

6 RISK CHARACTERIZATION – ENVIRONMENT

6.1 Screening for persistence, bioaccumulation, and toxicity ((G9): 5.1)

Based on an evaluation of the available data presented in Table 6.2, none of the substances met all three criteria (Table 6.1) to be considered as PBT substances.

Table 6.1: Standard criteria determining the PBT chemical

Criterion	PBT Criteria
Persistence	Half-life > 60 days in marine water, or > 40 days in freshwater, or > 180 days in marine sediment, or > 120 days in freshwater sediment
Bioaccumulation	BCF > 2,000 or Log $K_{ow} \geq 3$
Toxicity	Chronic NOEC < 0.01 mg/L

Table 6.2: PBT criteria evaluation

Chemical	Persistence (Yes/No)	Bioaccumulation (Yes/No)	Toxicity (Yes/No)
Bromate	No SW: 12 hours	No BCF = 3.2 Log K_{ow} = -4.6	No NOEC = 8 mg/L/7d (algae)
Chlorate	No Water: 15 days	No BCF = 3.2 Log K_{ow} = -4.63	No PBT Profiler
Perchlorate	No Water: 15 days	No BCF = 3.2 Log K_{ow} = -4.63	No NOEC = 0.75 mg/L/10d (fish)
Dibromochloromethane	No Water: 38 days	No BCF = 27.64 Log K_{ow} = 2.17	No NOEC = 3.2 mg/L/21day (fish)
Dichlorobromomethane	No FW: 5 days	No BCF = 7 Log K_{ow} = 0.22	No LC ₅₀ = 34 mg/L fish)
Bromoform	No FW: 7.1 days	No BCF = 14 Log K_{ow} = 2.4	No Lowest NOEC = 8.5 mg/L (fish)
Chloroform	No FW: 4.4 days	No BCF = 2.9-10.35 Log K_{ow} = 1.97	No Lowest NOEC = 1.5 mg/L (fish)
Monochloroacetic acid	No FW: 14 days	No Log K_{ow} = 0.22	No Lowest NOEC = 0.13 mg/L (algae)
Dichloroacetic acid	No FW: 4 days	No Log K_{ow} = 0.92	No EC ₃₀ = 1485 mg/L (algae)
Trichloroacetic acid	No FW: 40 days	No BCF = 0.1-1.7	No Lowest NOEC = 100 mg/L (algae)
Monobromoacetic acid	No Water: 8.7 days	No BCF = 3.2 Log K_{ow} = 0.41	No EC ₅₀ = 1.6 mg/L/21days (crustacean)
Dibromoacetic acid	No Water: 15 days	No BCF = 0.17 Log K_{ow} = 0.70	No LC ₅₀ = 69 mg/L/4 days (fish)
Tribromoacetic acid	No Water: 15 days	No BCF = 0.63 Log K_{ow} = 1.71	No LC ₅₀ = 68.7 mg/L/2 days (crustacean)
Bromochloroacetic acid	No Water: 15 days	No BCF = 3.2 Log K_{ow} = 0.61	No LC ₅₀ = 6.9 mg/L/4 days (fish)
Dibromochloroacetic acid	No Activated sludge: 100%(aerobic), 28 days	No Log K_{ow} = 1.62	No PBT Profiler
Dichlorobromoacetic acid	No Water: 37.5 days	No BCF = 1 Log K_{ow} = 1.53	No LC ₅₀ = 63.8 mg/L/2 days (crustacean)

Chemical	Persistence (Yes/No)	Bioaccumulation (Yes/No)	Toxicity (Yes/No)
Chloropicrin	No Water: 60 days	No Log K_{ow} = -0.25	No NOEC = 0.22 mg/L (fish)
Monobromoacetonitrile	No Water: 15 days	No Log K_{ow} = 0.2	No PBT Profiler
Dibromoacetonitrile	No Water: 38 days	No BCF= 3 Log K_{ow} = 0.47	No LC ₅₀ = 0.55 mg/L/4 days (fish)
2,4,6-Tribromophenol	No FW: 1.21 days	No BCF = 83-513 Log K_{ow} = 3.89	No Lowest NOEC = 0.10 mg/L (crustacean)
1,2,3-Trichloropropane	No Water: 37.5 days	No BCF= 59.33 Log K_{ow} = 3.17	No PBT Profiler
Sodium thiosulfate	No Biodegrades fast	No BCF = 3.162 Log K_{ow} = -4.53	No NOEC: 720 mg/L/2 days (algae)

6.1.1 Persistence ((G9): 5.1.1.1)

An evaluation of the environmental persistence data for Relevant Chemicals indicates that none of the substances are likely to be persistent in the environment.

6.1.2 Bioaccumulation ((G9): 5.1.1.2)

An evaluation of the available data for Relevant Chemicals indicates that the substances have extremely low potential for bioaccumulation. Although 1,2,3-trichloropropane and 2,4,6-tribromophenol has a reported Log K_{ow} of 3.17 and 3.89 (OECD, 2003) which is slightly above 3, the BCF is well below the criteria of 2000.

6.1.3 Toxicity tests ((G9): 5.1.2.3)

Due to the limited availability of chronic aquatic toxicity data for some substances, the evaluation for toxicity was based on all available data. In some cases acute endpoint data was utilized when available. For substances where no toxicity data points could be located, the data with respect to the other two PBT criteria is available and therefore, a PBT determination can still be made.

With the exception of substances having limited toxicity data, all other substances did not have chronic NOEC or E(L)C₅₀ values < 0.01 mg/L. Therefore, the criterion to be considered a toxic substance is not met.

6.2 Evaluation of the treated ballast water ((G9): 5.2)

This section is intended to evaluate the effects of preparations and their components on organisms and the environment when released with treated ballast water or accidentally during the process.

The effects of treated water by the Blue Zone™ BWMS on various marine organisms were evaluated in various acute and chronic ecotoxicity tests using seawater (32 PSU) and brackish water (21 PSU).

WET tests associated with Blue Zone™ treated seawater covering multiple test species indicated no acute and chronic ecotoxicity to any test organisms at discharge (day 5) as tested compared to control water. Even full strength effluent (100%) did not reveal any significant deleterious effects on any of the test species in both acute and chronic tests. Consequently, the de-ballasting water is expected to be non-toxic to aquatic organisms as well as to the marine environment in general. The actual NOEC for Blue Zone™ treated seawater was not measurable; the statistically determined NOEC was 100%.

Table 6.3 summarizes acute aquatic ecotoxicity data on two types of water associated with Blue Zone™ BWMS. Table 6.4 summarizes chronic aquatic ecotoxicity data on both of them. WET testing was performed by the institute of NeoEnBiz Co. Acute aquatic ecotoxicity tests were conducted with 5 taxonomic groups including bacteria, microalgae, rotifer, amphipod and fish on both full-strength seawater (32 PSU) and brackish water (21 PSU). Also, chronic aquatic ecotoxicity tests were conducted with 3 taxonomic groups including microalgae, rotifer and fish on both of them.

The samples for WET testing were collected directly from the discharge pipe on day 0 and especially at day 5, both before and after ballast water treatment and neutralization. All samples for WET testing were stored in proper sample containers at 4°C and transported to the designated laboratory within 12 hours of collection (please refer to appendix V, annex 1. sample transportation log sheet).

WET tests of the samples occurred within the time specified under standard laboratory procedures. All tests were performed according to laboratory protocols based on internationally recognized ISO, ASTM and/or USEPA. For the validation of test results, all possible performance criteria were checked according to OECD and other standard protocols. Especially for WET test with algae, the following three criteria should be carefully taken into account, and the detailed results are shown in section 2.2.2 of appendix V:

- .1 The biomass should increase exponentially by a factor of at least 16 within the 72-hour test period. This corresponds to a specific growth rate of 0.92 d^{-1} ;
- .2 The mean coefficient of variation for section-by-section specific growth rates (days 0-1, 1-2 and 2-3, for 72-hour tests) must not exceed 35 per cent (OECD 201); and
- .3 The coefficient of variation of average specific growth rates in the replicates during the whole test period must not exceed 10 per cent (OECD 201).

Table 6.3: The results of acute toxicity tests on day 5 sample using various marine organisms exposed to treated water both of before and after neutralization associated with Blue Zone™ BWMS

Salinity	Species Group	Species	Sample Type	Endpoint			Remark (Test Protocol)	
				NOEC (%)	LOEC (%)	LC ₅₀ or EC ₅₀ (%)		
Seawater (32 PSU)	Bacteria	<i>Vibrio fischeri</i>	Before N	100	>100	>100	ISO 11348	Luminescence inhibition (30 min)
			After N	100	>100	>100		
	Algae	<i>Skeletonema costatum</i>	Before N	100	>100	>100	ASTM E1218/ OECD201	Population growth inhibition (72 hrs)
			After N	100	>100	>100		
	Rotifer	<i>Brachionus plicatilis</i>	Before N	100	>100	>100	ASTM E1440	Mortality (24 hrs)
			After N	100	>100	>100		
	Amphipod	<i>Monocorophium acherusicum</i>	Before N	100	>100	>100	ASTM E1367	Mortality (96 hrs)
			After N	100	>100	>100		
	Fish	<i>Cyprinodon variegatus</i>	Before N	100	>100	>100	USEPA 821/R02 /012	Mortality (96 hrs)
			After N	100	>100	>100		
Brackish water (21 PSU)	Bacteria	<i>Vibrio fischeri</i>	Before N	100	>100	>100	ISO 11348	Luminescence inhibition (30 min)
			After N	100	>100	>100		
	Algae	<i>Skeletonema costatum</i>	Before N	100	>100	>100	ASTM E1218/ OECD201	Population growth inhibition (72 hrs)
			After N	100	>100	>100		
	Rotifer	<i>Brachionus plicatilis</i>	Before N	100	>100	>100	ASTM E1440	Mortality (24 hrs)
			After N	100	>100	>100		
	Amphipod	<i>Monocorophium acherusicum</i>	Before N	100	>100	>100	ASTM E1367	Mortality (96 hrs)
			After N	100	>100	>100		
	Fish	<i>Cyprinodon variegatus</i>	Before N	100	>100	>100	USEPA 821/R02 /012	Mortality (96 hrs)
			After N	100	>100	>100		

N=Neutralization

A chronic aquatic ecotoxicity test on two types of water associated with the Blue Zone™ BWMS was conducted. The following Table 6.4 summarizes the data of chronic aquatic ecotoxicity test result only on day 5 for both seawater and brackish water associated with the Blue Zone™ BWMS.

Table 6.4: The results of chronic ecotoxicity tests on day 5 sample using various marine organisms exposed to treated water both of before and after neutralization associated with Blue Zone™ BWMS

Salinity	Species Group	Species	Sample Type	Endpoint			Remark (Test Protocol)	
				NOEC (%)	LOEC (%)	LC ₅₀ or EC ₅₀ (%)		
Seawater (32 PSU)	Algae	<i>Skeletonema costatum</i>	Before N	100	>100	>100	ASTM E1218/ OECD201	Growth rate (96 hrs)
			After N	100	>100	>100		
	Rotifer	<i>Brachionus plicatilis</i>	Before N	100	>100	>100	Janssen et al., 1994	Population Growth rate (72 hrs)
			After N	100	>100	>100		
	Fish	<i>Cyprinodon variegatus</i>	Before N	100	>100	>100	USEPA 821/R02/014	Growth rate (7 days)
			After N	100	>100	>100		
Brackish water (21 PSU)	Algae	<i>Skeletonema costatum</i>	Before N	100	>100	>100	ASTM E1218/ OECD201	Growth rate (96 hrs)
			After N	100	>100	>100		
	Rotifer	<i>Brachionus plicatilis</i>	Before N	100	>100	>100	Janssen et al., 1994	Population Growth rate (72 hrs)
			After N	100	>100	>100		
	Fish	<i>Cyprinodon variegatus</i>	Before N	100	>100	>100	USEPA 821/R02/014	Growth rate (7 days)
			After N	100	>100	>100		

N=Neutralization

6.2.1 Determination of holding time

Even though the various factors such as half-life, decay, dosage rates, system parameters and toxicity data are very important factors to determine holding time, the information on the factors is not sufficient to evaluate the holding time.

In the laboratory scale test evaluating the exact holding time has been difficult due to lack of data related to TRO and toxic degradation with time. Consequently, the total evaluation of holding time will be decided at the Final Approval.

6.3 Risk characterization and analysis

6.3.1 Prediction of discharge and environmental concentrations

The MAMPEC-BW Model version 3.0 was used to calculate the PEC of Relevant Chemicals in the GESAMP-BWWG Model Harbour. It can be used in modified form, to calculate the concentrations constantly released into the water by other processes, for example ballast water treatment. The model's applicability to any chemical substances made it a useful tool for environmental impact studies.

PEC for all Relevant Chemicals under the Blue Zone™ BWMS was calculated with the highest concentration (maximum discharge) of any chemical analysis result among day 0 or day 5 regardless of control and treated water, and both of before and after the neutralization process. Also, PEC was modelled on both seawater and brackish water, respectively (Table 6.5).

**Table 6.5: Results of PECs on ballast water discharged in the
GESAMP-BWWG Model Harbour**

Chemicals	Seawater (32 PSU)		Brackish water (21 PSU)	
	Max. discharge conc. (mg/L)	PEC (µg/L)	Max. discharge conc. (mg/L)	PEC (µg/L)
Bromate (Sodium)	3.3E-02	8.63E-01	4.8E-02	1.26E+00
Chlorate	1.7E-01	4.58E+00	1.7E-01	4.58E+00
Perchlorate	8.6E-04	2.32E-02	1.5E-03	4.09E-02
Dibromochloromethane	4.6E-03	3.68E-02	8.0E-03	6.40E-02
Dichlorobromomethane	6.5E-03	5.07E-02	1.4E-02	9.12E-03
Bromoform	1.1E-01	1.17E+00	1.2E-01	1.34E+00
Chloroform	7.9E-03	5.36E-02	4.0E-02	2.69E-01
Monochloroacetic acid	1.0E-04	2.69E-03	1.0E-04	2.69E-03
Dichloroacetic acid	4.4E-04	1.15E-02	3.5E-04	9.12E-03
Trichloroacetic acid	7.0E-05	1.88E-03	1.9E-04	5.12E-03
Monobromoacetic acid	4.8E-04	1.29E-02	2.2E-04	5.91E-03
Dibromoacetic acid	9.8E-03	2.64E-01	1.1E-02	2.88E-01
Tribromoacetic acid	3.0E-03	7.97E-02	5.0E-05	1.35E-03
Bromochloroacetic acid	1.0E-03	2.72E-02	8.3E-04	2.23E-02
Dibromochloroacetic acid	1.0E-04	2.69E-03	7.5E-03	2.03E-01
Dichlorobromoacetic acid	2.6E-04	7.00E-03	6.0E-05	1.62E-03
Chloropicrin	1.4E-03	3.82E-02	1.3E-03	3.61E-02
Monobromoacetonitrile	1.6E-03	4.31E-02	3.1E-04	8.35E-03
Dibromoacetonitrile	2.0E-05	5.39E-04	4.5E-03	1.21E-01
2,4,6-Tribromophenol	1.0E-03	2.69E-02	1.0E-03	2.69E-02
1,2,3-Trichloropropane	1.3E-03	1.37E-02	1.3E-03	1.37E-02

6.3.2 Effects assessment

The data for the substances associated with use of the Blue Zone™ BWMS indicate that there is a low potential for bioaccumulation, sediment adsorption, and persistence in the aquatic environment. No effects or risks in the form of secondary (food chain) poisoning or to sediment species are anticipated. As such, aquatic toxicity presents the only likely potential risk for aquatic organisms.

Whole effluent toxicity testing (acute and chronic endpoints) of treated water both before and after the neutralization process suggests no apparent toxicity for any species or endpoints tested (L(E)C₅₀ and/or NOEC values of ≥ 100% ballast water sample). In light of these results, although aquatic toxicity is identified as having the most potential for risk to aquatic organisms, WET testing results suggest that the potential risk is low.

6.3.3 Effects on aquatic organisms

Predicted No Effect Concentrations (PNEC) values were calculated using the aquatic toxicity data set endpoints and the appropriate assessment factor. A thorough literature review of available PNEC values for the chemicals was conducted (data presented in Table 6.6).

**Table 6.6: Predicted No Effect Concentration (PNEC)
for chemicals detected in treated ballast water at discharge**

Chemical	**Toxicity Value (mg/L)	Assessment Factor	PNEC (µg/L)	Comment(s)
Bromate	8	100	80	Lowest chronic toxicity value
Chlorate	-	-	1150	*From ECHA
Perchlorate	-	-	100	*From ECHA
Dibromochloromethane	34	1000	34	Lowest acute toxicity value
Dichlorobromomethane	67.4	1000	67.4	Lowest acute toxicity value
Bromoform	8.5	100	85	Lowest chronic toxicity value
Chloroform	-	-	15	*From ECHA
Monochloroacetic acid	8.5	100	85	Lowest chronic toxicity value
Dichloroacetic acid	23	1000	23	Lowest acute toxicity value
Trichloroacetic acid	100	1000	100	Lowest acute toxicity value
Monobromoacetic acid	1.4	1000	1.4	Lowest acute toxicity value
Dibromoacetic acid	69	1000	69	Lowest chronic toxicity value
Tribromoacetic acid	69	1000	69	Assumed to be the same value as that for dibromoacetic acid
Bromochloroacetic acid	69	1000	69	Assumed to be the same value as that for dibromoacetic acid
Dibromochloroacetic acid	55.6	1000	55.6	IMO 2012
Dichlorobromoacetic acid	63.8	1000	63.8	ECOSAR, 2011
Chloropicrin	0.022	10	2.2	ECOSAR, 2011
Monobromoacetonitrile	0.55	1000	0.55	Assumed to be the same value as that for dibromoacetonitrile
Dibromoacetonitrile	0.55	1000	0.55	Lowest acute toxicity value
2,4,6-Tribromophenol	0.1	100	1	Lowest chronic toxicity value
1,2,3-Triichloropropane	-	-	8.8	*From ECHA

* PNEC value direct from ECHA (European Chemicals Agency) Web-database

** Toxicity Values from appendix XII

6.3.4 Comparison of effect assessment with discharge toxicity

The information reviewed for degradation and bioaccumulation of the substances related to the use of the Blue Zone™ BWMS suggest that potential effects from these mechanisms cannot be reasonably anticipated. The effects assessment establishes that there is potential for reaction of the Active Substances with organic matter and formation of DBPs. This has been confirmed by data from ballast water discharge samples analysed for DBPs. The presence of DBPs in disinfected water can potentially result in toxic effects to aquatic organisms. All toxicity tests both before and after neutralization with sodium thiosulfate resulted in L(E)C₅₀ and/or NOEC values $\geq 100\%$. Ballast water sample discharge toxicity testing results are consistent with the overall effects assessment that the potential effects are related to aquatic toxicity, rather than bioaccumulation or persistence in the environment. Further, the toxicity observed with neutralized discharge samples was not found in any of the species tested.

7 RISK ASSESMENT

7.1 Risk to safety of ship

7.2 Fire and explosion

While ozone itself is not flammable, it is a strong oxidant and may accelerate, even initiate, combustion, or cause explosions. Thus the space where the ozone generator is installed should be properly vented after use. Ozone must be contained within ozone-resistant tubing and pipes from the generation point to the application point. Any leaks must be repaired before further use.

To detect possible ozone gas leakage from generator or gas venting device, an ozone gas detector with alarm will be provided at the pump room or engine room in which the Blue Zone™ BWMS will be installed. Under normal operation, ozone gas leakage does not occur. In the case of leakage the system will be designed to shut down.

Considering it is important to supply air continuously, two redundant air blowers are provided. Should the one in operation fail, another will continue to operate automatically. Airflow switches are installed in the vent line to monitor the air blowers' failure.

7.1.2 Storage and handling of the substances

The Blue Zone™ BWMS does not require the storage of any chemicals on board except for the solution of sodium thiosulfate as a neutralizing agent. The solution of sodium thiosulfate is the only chemical substance that needs to be stored and handled on board. The amount of stored sodium thiosulfate will vary depending on the amount of ballast water treated and will be specific to each installation. Sodium thiosulfate is stored in vented stainless steel or polyethylene (PE) or fiber reinforced plastic (FRP) tanks.

Sodium thiosulfate of 15% concentration in weight shall be used. This can be purchased easily in most cities around the world. The solution of sodium thiosulfate in tanks shall be placed on vessel by crane from a land facility. The neutralization unit shall be installed in the pump room or engine room of the vessel and a refilling pipe is to be installed. The solution of sodium thiosulfate shall be transferred from a storage tank on the vessel to a feeder tank in the pump room or engine room through a refilling pipe. A level transmitter installed at the feeder tank monitors the level of the feeder tank. If the feeder tank is empty, the neutralization unit generates an alarm and the system shall be shut down.

When handling the solution of sodium thiosulfate, the crew should be equipped with splash goggles, gloves and boots. A self-contained breathing apparatus should be used to avoid inhalation of the vapour of sodium thiosulfate. If the eye of the crew is contaminated by the solution, the crew should flush eyes with running cold water immediately and keep eyelids open. If the concentrated solution is exposed to the skin, the crew should wash the contaminated skin with running water and a non-abrasive soap gently and thoroughly. Sodium thiosulfate is non-flammable and therefore does not provide any fire risk.

7.1.3 Corrosion

Corrosion is electrochemical oxidation of metals in reaction with an oxidant. The chemicals produced by the ozone generator are known to be strong oxidants.

Ozone reacts with seawater and produces a number of corrosive compounds (e.g. several forms of chlorine). These corrosive compounds were found to decay after a period of some hours to more than one week following treatment. The decay rate is a function of ballast water characteristics (presence of organic compounds, metal ions and organisms). Ozonation strongly reduces the bacterial content in the ballast water. This indicates that bacterial corrosion may be reduced or potentially eliminated as a result of ozonation. However, existing literature indicate that extremely high corrosion rates may occur if ozonation of ballast water is used in ships where microbiological corrosion has already been established (DNV, 1993).

Based on literature, additional corrosive effect did not significantly occur by chlorine of 5 mg/L or lower when were metals exposed to seawater (Kim and Jang, 2009; Song *et al.* 2009). Since the treated water at day 0 had TRO as Cl₂ concentration lower than 5 mg/L, the corrosive effect by excessive oxidants may occur during some days. The chemical analysis results showed that TRO as Cl₂ in treated water decreased to negligible levels after 5 days of storage. Therefore the period that the TRO as Cl₂ concentration is lower than 5 mg/L in the ballast water will not be long enough to affect the tank surface.

Further experiments adopting a longer test period over 6 months and more realistic exposure conditions should be conducted with coated/uncoated metals and also with non-metal surfaces such as rubber and PVC related to corrosivity in following research.

7.2 Risk to human health

7.2.1 Health effect in humans

For this system, leaking ozone densitometers will be provided around the ozone generator and close to the transfer route to monitor the leaking ozone continuously. If leaking ozone is detected, visible and audible alarms are raised at the bridge and the location of the system to stop operation of the generator and urge the crew to evacuate. Therefore, there is no possibility of exposure to the crew in the normal operation of the ozone, the Active Substance of this system.

Due to the technology used, humans will not be exposed to the Blue Zone™ BWMS during the operating process on board. During the recommended operating procedures the possibility of exposure will be minimal and limited to short term contact when connecting the storage tank to the dosage line. Direct contact during this operation is minimized by the recommended handling procedures that include the appropriate personal protective equipment, gloves, goggles and if needed respiratory protection. As the main hazard of the product is due to local irritation/corrosion at the site of contact and there is no immediate

concern for mutagenicity or carcinogenicity, the product can be handled safely in this application.

Table 7.1: Risk Characterization Ratios (RCR) estimated for daily occupational exposure.

Substance	Sampling		Cleaning tank		Tank inspection	Normal work	Total worker RCR
	Inhalation	Dermal	Inhalation	Dermal	Inhalation	Inhalation	
Bromate	1.5.E-17	1.3.E-03	1.4.E-18	1.3.E-03	1.2.E-21	6.1.E-21	2.7.E-03
Dibromochloro methane	1.0.E-03	1.0.E-05	9.1.E-05	1.0.E-05	8.2.E-08	4.1.E-07	1.1.E-03
Dichlorobromo methane	1.7.E-08	7.9.E-06	1.5.E-09	7.9.E-06	1.3.E-12	6.6.E-12	1.6.E-05
Bromoform	1.1.E-02	2.1.E-04	1.0.E-03	2.1.E-04	9.0.E-07	4.5.E-06	1.3.E-02
Chloroform	4.8.E-03	4.7.E-06	4.3.E-04	4.7.E-06	3.9.E-07	1.9.E-06	5.3.E-03
Dichloroacetic acid	2.4.E-14	1.0.E-06	2.1.E-15	1.0.E-06	1.9.E-18	9.7.E-18	2.0.E-06
Monobromoacetic acid	8.2.E-09	1.3.E-05	7.3.E-10	1.3.E-05	6.6.E-13	3.3.E-12	2.5.E-05
Dibromoacetic acid	7.3.E-08	1.6.E-04	6.5.E-09	1.6.E-04	5.8.E-12	2.9.E-11	3.3.E-04
Tribromoacetic acid	1.7.E-08	5.0.E-05	1.5.E-09	5.0.E-05	1.3.E-12	6.6.E-12	9.9.E-05
Bromochloroacetic acid	4.5.E-09	2.8.E-06	4.0.E-10	2.8.E-06	3.6.E-13	1.8.E-12	5.6.E-06
Dibromochloroacetic acid	5.3.E-13	2.1.E-04	4.7.E-14	2.1.E-04	4.2.E-17	2.1.E-16	5.3.E-13
Dichlorobromoacetic acid	5.3.E-14	6.8.E-06	4.7.E-15	6.8.E-06	4.2.E-18	2.1.E-17	5.3.E-14
Chloropicrin	1.1.E-08	5.4.E-06	9.8.E-10	5.4.E-06	8.8.E-13	4.4.E-12	1.1.E-05
Monobromoacetonitrile	1.7.E-12	4.3.E-06	1.5.E-13	4.3.E-06	1.4.E-16	7.0.E-16	8.7.E-06
Dibromoacetone	9.7.E-07	2.4.E-05	8.6.E-08	2.4.E-05	7.7.E-11	3.9.E-10	4.9.E-05

Table 7.2: Risk Characterization Ratios (RCR) estimated for daily public exposure.

Substances	Swimming			Eating seafood	Public total RCR
	Inhalation	Dermal	Chemical swallowed	Eating fish	
Bromate	9.7E-23	1.4.E-04	1.83.E-05	N.C.	1.6E-04
Dibromochloromethane	2.2E-09	3.7.E-07	4.78.E-08	2.31E-06	2.7E-06
Dichlorobromomethane	9.6E-14	7.6.E-07	9.82.E-08	3.69E-06	4.6E-06
Bromoform	3.0E-08	9.3.E-06	1.20.E-06	2.44E-05	3.5E-05
Chloroform	4.8E-08	7.8.E-07	1.00.E-07	1.56E-06	2.5E-06
Dichloroacetic acid	5.7E-20	4.0.E-08	5.15.E-09	8.29E-09	5.3E-08
Monobromoacetic acid	3.1E-14	8.0.E-07	1.03.E-07	1.77E-06	2.7E-06

Substances	Swimming			Eating seafood	Public total RCR
Dibromoacetic acid	4.8E-13	1.8.E-05	2.30.E-06	2.10E-06	2.2E-05
Tribromoacetic acid	9.9E-14	4.9.E-06	6.37.E-07	2.16E-06	7.7E-06
Bromochloroacetic acid	2.5E-14	2.6.E-07	3.34.E-08	5.75E-07	8.7E-07
Dibromochloroacetic acid	1.9E-18	1.3.E-05	1.62.E-06	2.75E-05	4.2E-05
Dichlorobromoacetic acid	2.0E-19	4.3.E-07	5.59.E-08	9.49E-07	1.4E-06
Chloropicrin	7.2E-14	5.9.E-07	7.63.E-08	3.28E-06	3.9E-06
Monobromoacetoneitrile	1.1E-17	4.7.E-07	6.10.E-08	5.17E-07	1.1E-06
Dibromoacetoneitrile	3.2E-12	1.3.E-06	1.71.E-07	2.71E-06	4.2E-06

7.2.2 Human Exposure Scenario

The possible receptors here can be (1) occupational, the crew and/or port state inspectors for the operation and maintenance of the BWMS (the operators), and (2) general public, general human populations, which can be exposed to the chemicals of concerns (COCs) via the environment where treated ballast water is discharged. For the general public, exposure may occur by consumption of seafood and swimming in the surrounding area.

Different exposure scenarios should be developed for each receptor group. All human receptors can be exposed to the COCs via ingestion or dermal as well as the inhalation route. Depending on the scenario developed, the importance of each exposure route can be varied.

The operation and maintenance may include the usual operation of the system during ballasting and de-ballasting, cleaning work, repairing work and all other maintenance processes. Since the operator should wear suitable protective clothing, gloves and shoes, the possibility for the exposure of COCs in the water treated by the BWMS to operators will be very low. To assess the potential risk under worst-case situation, it is assumed that the operators do not wear protective clothing and gloves.

The Blue Zone™ BWMS is a closed system, so it is very unlikely that the operator is exposed to the COCs vaporized from pipeline or ballast tank. However, the maximum level of COCs was estimated and used for the risk assessment of both occupational and public exposure.

No occupational or public exposure (average daily dose) to COCs exceeded DNEL in this assessment (Table 5.3). RCRs of the aggregated exposure of all scenarios also were all less than 1 indicating that the Blue Zone™ BWMS may pose negligible risk to both workers and the general public.

7.3 Risk to the aquatic environment

Data for the chemicals associated with the Blue Zone™ BWMS indicate that there is a low potential for bioaccumulation, sediment adsorption, and persistence in the aquatic environment. No effects or risks in the form of secondary (food chain) poisoning or to sediment species are anticipated. As such, ecotoxicity presents the only likely potential risk for aquatic organisms.

Therefore, WET testing of the treated ballast discharge indicates that unacceptable risks to the aquatic environment are not expected from use of the Blue Zone™ BWMS. Ecotoxicity test results revealed no measurable levels of potentially toxic substances and no significant acute and chronic effects of the de-ballasting samples on aquatic organisms. No apparent environmental risks could therefore be identified.

Most of the ecotoxicity data from the literature showed that the remaining levels of Active Substance and potential Relevant Chemicals are not considered toxic to most aquatic organisms. In conclusion, no test results found any measurable levels of potentially toxic substances and no acute or chronic effects from the de-ballasting water on aquatic organisms.

Table 7.3: PEC/PNEC ratios on Relevant Chemicals in GESAMP-BWWG Model Harbour

Chemicals	Seawater (34 PSU)			Brackish water (21 PSU)		
	PEC (µg/L)	PNEC (µg/L)	PEC/PNEC	PEC (µg/L)	PNEC (µg/L)	PEC/PNEC
Bromate (Sodium)	8.6E-01	80	1.1E-02	1.3E+00	80	1.6E-02
Chlorate	4.6E+00	1150	4.0E-03	4.6E+00	1150	4.0E-03
Perchlorate	2.3E-02	100	2.3E-04	4.1E-02	100	4.1E-04
Dibromochloromethane	3.7E-02	34	1.1E-03	6.4E-02	34	1.9E-03
Dichlorobromomethane	5.1E-02	67.4	7.5E-04	9.1E-03	67.4	1.4E-04
Bromoform	1.2E+00	85	1.4E-02	1.3E+00	85	1.6E-02
Chloroform	5.4E-02	15	3.6E-03	2.7E-01	15	1.8E-02
Monochloroacetic acid	2.7E-03	85	3.2E-05	2.7E-03	85	3.2E-05
Dichloroacetic acid	1.2E-02	23	5.0E-04	9.1E-03	23	4.0E-04
Trichloroacetic acid	1.9E-03	100	1.9E-05	5.1E-03	100	5.1E-05
Monobromoacetic acid	1.3E-02	1.4	9.2E-03	5.9E-03	1.4	4.2E-03
Dibromoacetic acid	2.6E-01	69	3.8E-03	2.9E-01	69	4.2E-03
Tribromoacetic acid	8.0E-02	69	1.2E-03	1.4E-03	69	2.0E-05
Bromochloroacetic acid	2.7E-02	69	3.9E-04	2.2E-02	69	3.2E-04
Dibromochloroacetic acid	2.7E-03	55.6	4.8E-05	2.0E-01	55.6	3.7E-03
Dichlorobromoacetic acid	7.0E-03	63.8	1.1E-04	1.6E-03	63.8	2.5E-05
Chloropicrin	3.8E-02	2.2	1.7E-02	3.6E-02	2.2	1.6E-02
Monobromoacetonitrile	4.3E-02	0.55	7.8E-02	8.4E-03	0.55	1.5E-02
Dibromoacetonitrile	5.4E-04	0.55	9.8E-04	1.2E-01	0.55	2.2E-01
2,4,6-Tribromophenol	2.7E-02	1	2.7E-02	2.7E-02	1	2.7E-02
1,2,3-Trichloropropane	1.4E-02	8.8	1.6E-03	1.4E-02	8.8	1.6E-03

Risk assessment to the aquatic environment by chemicals in ballast water was carried out by calculating PEC/PNEC ratio. If the PEC/PNEC ratio is less than or equal to 1, the chemical is of no immediate concern. If the PEC/PNEC ratio is greater than 1, the substance should be of concern.

The PEC/PNEC calculated for chemicals are all less than 1 even under the worst-case scenario, so the ballast water treated by Blue Zone™ BWMS has low potential risk for the aquatic environment. Risk assessment results for aquatic environment are summarized in Table 7.3.

Overall, the chemical analyses (Table 3.5) and the toxicity tests (Tables 6.3 and 6.4) have led to the conclusion that there is negligible risk to the aquatic environment. Neither potential hazardous substances nor significant acute toxicity in the treated water samples were significantly observed for the Blue Zone™ BWMS evaluated in this report.

Under worst-case emission scenarios, discharged water will be diluted at least dozens of times or more, so any residual toxicity would seem to be insignificant both during and after de-ballasting from the ship if realistic conditions are relevant to the test conditions in this report.

8 ASSESSMENT REPORT ((G9): 4.3)

The constituents associated with the Blue Zone™ BWMS were evaluated for a variety of endpoints, including toxicity, bioaccumulation, and persistence in the environment. The physical and chemical properties were evaluated to assess the proper chemical handling and/or storage, and risks related to fire and explosion. Treated ballast water discharge and risks of the COCs to human health were also evaluated. As the Active Substance is generated on-board as required and neutralized prior to discharge, it is the treated ballast water and DBPs potentially present that are the most important to consider for this evaluation.

During the laboratory scale test runs of the Blue Zone™ BWMS meeting the ballast water performance standard concerning biological efficacy, the amount of Active Substance and Relevant Chemicals were measured and the acute and chronic WET tests using representative marine species of algae, invertebrates and fish were conducted for treated seawater (32 PSU) and brackish water (21 PSU).

The human health risk assessment data showed that the Blue Zone™ BWMS poses negligible risk to both ships crews conducting ballast water sampling and cleaning and the general public who may swim and eat seafood near the discharging point.

The PEC in the GESAMP-BWWG Model Harbour was predicted by using the modelling of MAMPEC-BW Model 3.0 and the PNEC was determined from the selected aquatic toxicity data and assessment factors. Overall, the PEC/PNEC ratio of Relevant Chemicals does not exceed 1, which means ecological risks posed by the Blue Zone™ system are negligible, even when the PECs were modelled based on the maximum concentration with salinities of 21 or 32 PSU.

The Blue Zone™ BWMS is not likely to cause health risks for humans or the aquatic environment.